PRESSURE SCIENCE INCORPORATED *engineers and manufacturers of* *products*

FINAL REPORT MS-I

DESIGN AND DEVELOPMENT OF AN ENCLOSURE SEAL

Contract No. NAS 8-11606

Pressure Science Incorporated
Beltsville, Maryland

Prepared by:
John F. Daugherty
Project Manager

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1. Introduction

The following report covers work performed by Pressure Science Incorporated of Beltsville, Maryland under Contract No. NAS 8-11606. The purpose of this contract was to design and develop a twenty-inch diameter metal enclosure seal. The seal is required to maintain nitrogen gas at one atmosphere in an aluminum or beryllium enclosure consisting of a cylindrical ring and two hemispherical covers. Further seal requirements are that it withstand up to 12 assemblies and disassemblies of the covers, seal in ambient pressures from atmospheric down to 10^{-6} torr, seal in ambient temperatures from -25°C to 75°C, and seal for storage periods up to one year.

Pressure Science Incorporated has been engaged for the past five years in the development of metal seals. These seals have been tested and used in applications over wide ranges of temperature and pressure. Mount Vernon Research Association of Alexandria, Virginia has performed leakage tests using the metal C-Ring seal at 10^{-8} torr over the temperature range of 400°C to -200°C (five cycles). A leak detector having a maximum sensitivity of 5×10^{-10} cc/sec was used and no leak was detected. Based upon these results, the C-Ring was selected for the twenty-inch diameter enclosure seal.

Although zero leakage was not maintained in the testing done under this contract, the results indicate steps to be taken to achieve zero leakage. This report will point out that decreased flange deflections on the hemispherical covers and specific changes in the sealing surface characteristics are required.

2. Theoretical Analysis of the C-Ring Seal

The installation of the C-Ring seal in a prototype enclosure is shown in Figure 1. Previously an analysis of the C-Ring Seal was performed to determine the effects of pressure, initial squeeze force, friction between the seal and the sealing surfaces, size and wall thickness on operating and sealing characteristics of the seal.

2.1. Assumptions: The following assumptions have been made to perform the seal analysis. While these assumptions do affect the accuracy of the numerical results obtained, they do not change the relative importance of the various parameters.

a. The diameter of the ring is large; therefore, hoop stresses are small since hoop deflections are small.

b. Redistribution of the forces due to strains in the seal itself have been neglected.

c. The stresses developed are uniformly distributed across the seal thickness.

d. Seal diameter is large compared to R.

2.2. <u>Nomenclature</u> (See Figure 2)

F = sealing contact force - #/in

μ = coefficient of friction

F_p = sealing force due to pressure - #/in

T = tangential force - #/in

θ = angle - degrees

t = wall thickness - in

M = bending moment

f = shearing force - sealing

F_0 = initial squeeze force - #/in

V = shear force - #/in

R = radius

P = pressure - psi

Counterclockwise moments positive

2.3. <u>Theoretical Analysis</u>:

Let $K = R + \frac{t}{2}$

(1) $f = \mu(F) = \mu(F_p + F_0)$

(2) $M_0 = f\frac{t}{2}$ (due to shifting f to the mean radius)

(3) $\Sigma F_x = 0$

$V = PK - f$

(4) $\Sigma F_y = 0$

$T = F - P(R - \frac{t}{2})$

(5) $\Sigma M_\theta = 0$

$$M_\theta = -\frac{ft}{2} FR \sin\theta + (Pt - f)(R)(1 - \cos\theta) + PR(R - \frac{t}{2})(1 - \cos\theta)$$

NOTE: The last term of Eq. (5) is due to the pressure on the inside of the C-ring.

Substituting Eqs. (3) and (4) into (5) we obtain:

(6) $M_\theta = VK - \frac{PKt}{2} - TR \sin\theta - PR(R - \frac{t}{2})\sin\theta - VR \cos\theta.$

Using the Theory of Least Work:

$$U = 4\int_0^{\frac{W}{2}} \frac{M_\theta^2}{2EI} Rd\theta$$

(7) $\frac{\partial U}{\partial T} = 0 = \int_0^{\frac{\pi}{2}} M_\theta \frac{\partial M_\theta}{\partial T} d\theta$

(8) From Eq. (6): $\frac{\partial M_\theta}{\partial T} = -R \sin\theta$

Substituting Eqs. (6) and (8) into (7):

(9) $$0 = \int_0^{\frac{\pi}{2}} \left[-VKR \sin\theta + \frac{PRKt}{2} \sin\theta + TR^2 \sin^2\theta + PR^2(R - \frac{t}{2}) \sin^2\theta + VR^2 \cos\theta \sin\theta \right] d\theta$$

Solving Eq. (9)

(10) $$T = \frac{4}{\pi} \frac{VK}{R} - \frac{2}{\pi} \frac{PKt}{R} - P(R - \frac{t}{2}) - \frac{2V}{\pi}.$$

Substituting Eq. (10) into (6):

(11) $$M_\theta = VK(1 - \frac{4}{\pi} \sin\theta) + VR(\frac{2}{\pi} \sin\theta - \cos\theta) + PKt(\frac{2}{\pi} \sin\theta - \frac{1}{2}).$$

Using again the Theory of Least Work:

(12) $$\frac{\partial U}{\partial V} = 0 - \int_0^{\frac{\pi}{4}} M_\theta \frac{\partial M_\theta}{\partial V} d\theta$$

(13) $$\frac{\partial M_\theta}{\partial V} = K(1 - \frac{4}{\pi} \sin\theta) + R(\frac{2}{\pi} \sin\theta - \cos\theta).$$

Substituting Eqs. (11) and (13) into (12):

(14) $$0 = \int_0^{\frac{\pi}{2}} \left[K(1 - \frac{4}{\pi} \sin\theta) + R(\frac{2}{\pi} \sin\theta - \cos\theta) \right] \left[VK(1 - \frac{4}{\pi} \sin\theta) + VR(\frac{2}{\pi} \sin\theta - \cos\theta) + PKt\,(\frac{2}{\pi} \sin\theta - \frac{1}{2}) \right] d\theta.$$

Solving Eq. (14), we obtain:

(15) $$\frac{V}{P} = \frac{Kt[K(\pi^2 - 8) + 2R(2 - \pi)]}{2K^2(\pi^2 - 8) - 8RK(\pi - 2) + R^2(\pi^2 - 4)}.$$

Substituting Eq. (15) into Eq. (3):

$$(16) \quad \frac{f}{P} = K - \frac{Kt[K(\pi^2 - 8) + 2R(2 - \pi)]}{2K^2(\pi^2 - 8) - 8RK(\pi - 2) + R^2(\pi^2 - 4)}.$$

Substituting Eq. (15) into Eq. (10):

$$(17) \quad \frac{T}{P} = \frac{2}{\pi}\left\{\frac{Kt[K(\pi^2 - 8) + 2R(2 - \pi)]}{2K^2(\pi^2 - 8) - 8RK(\pi - 2) + R^2(\pi^2 - 4)}\left[\frac{2K}{R} - 1\right]\right\} - \left(\frac{2}{\pi}Kt + (R - \frac{t}{2})\right)$$

Substituting Eq. (17) into Eq. (4):

$$(18) \quad \frac{F}{P} = \frac{2}{\pi}\left\{\frac{Kt[K(\pi^2 - 8) + 2R(2 - \pi)]}{2K^2(\pi^2 - 8) - 8RK(\pi - 2) + R^2(\pi^2 - 4)}\left[\frac{2K}{R} - 1\right]\right\} - \frac{2}{\pi}Kt.$$

Using Eqs. (1), (16) and (18) a relationship has been obtained relating F_0 and M as a function of pressure.

These equations have been programmed and run on a high speed computer. The results of this analysis have been utilized in the detailed design of the enclosure seal.

3. Seal Configuration and Cavity Design

Past sealing experience has demonstrated that if relative motion between the seal and sealing surfaces occurs a leak will develop. The relative motion can be caused by pressure or temperature changes which deflect either the seal or the sealing surfaces relative to one another. Thus to obtain a no leak seal installation the seal must follow any deflections of the sealing surfaces without sliding relative to the sealing surfaces. In order to accomplish this result an integrated analysis of the seal and cavity must be made for all environmental conditions. Based on the analysis of the C-Ring seal and cavity design, the seal configuration shown in Figure 3 was established. The seal details are shown in Figure 4.

3.1. Cavity Design: Based on previous seal experience a force of 100 #/linear inch between the seal and the sealing surface is adequate for a no leak seal. Sixty four No. 5-40 x 3/8 screws spaced at one inch intervals around the flange are sufficient to generate the required sealing force and keep the deflection between screws to less than 0.003 inch. Since the proposed C-Ring seal of Figure 4 has a spring back of approximately 0.020 inch, the resultant variation in sealing force around the seal circumference would be approximately 15%. A seal developed for the aluminum flanges should function satisfactorily if Beryllium is used.

3.2. <u>Sealing Surface Deflection Due to Applied Pressure Differential</u>: Referring to Figure 5, the basic deflection problem is whether the sealing surfaces will deflect or open with an internal pressure of one atmosphere and an outside pressure of 10^{-6} Torr. F_p and M_p are the force and bending moments respectively transmitted from the spherical shell to the flange. Using a pressure differential of 15 psi F_p is calculated to be 75 lb/in and M_p = .654 in-lb/in. Due to the small value of M_p it has been neglected in the following calculations. If the sealing surfaces deflect, the force F_{B2} will go zero or become negative.

Let F_B = 600 lb/in (Based on 64 screws on a 1" circumferential spacing)

F_s = 100 lb/in

F_p = 75 lb/in

$\Sigma F = 0$ (See Figure 5)

(1) $F_{B1} - F_B + F_s + F_{B2} + F_p = 0$

$\Sigma M_A = 0$

(2) $.046F_{B2} + .193F_s - .468F_B + .656F_{B1} = 0$

Solving (1) and (2) for F_{B2} we obtain

F_{B2} = 192.5 lb/in

Thus with $F_{B2} > 0$ the sealing surfaces should not deflect or open when an internal pressure is applied.

3.3. <u>Contact Stress Between the Metal C-Ring Seal and the Sealing Surfaces</u>: The calculated value of contact stress for a 1/8" radius metal seal against a plane aluminum surface is 50,000 psi at 100 lb/in sealing force. This magnitude of contact stress is sufficient to plastically deform the soft metal plating into the surface finish irregularities. The softer metal plating on the seal should also prevent coining of the aluminum or beryllium surfaces and allow for re-useability.

3.4. Manufacturing Drawings: Manufacturing drawings of the Cylindrical Rings (PSI Drawing No. D-1644), Hemispherical Covers (PSI Drawing No. F-1643), and the C-Rings (PSI Drawing No. C-1645) were prepared following the analytical design of the C-Rings and prototype enclosure and are enclosed. The material for the rings was certified to be Aluminum 6061-T6. It was important to have high strength material in the rings because of the tapped screw threads.

4. Manufacturing of C-Ring Seals and Prototype Enclosure

4.1. Cylindrical Rings: The rings were machined from 6061-T6 forgings in accordance with PSI Drawing No. D-1644. During testing it was established that the as-machined finishes of the sealing surfaces in the cavities were inadequate. In general the finish had an rms value of 32 or less, but not as low as 16. In some places, light chatter-marks from the cutting tool could be observed on the sealing surfaces as machined. Such a surface imperfection can cause a leak using a metal seal. A flat surface of 16 rms finish having concentric lay has been found to be required for gas tight seals using plated C-Rings.

During the testing phase the rings were set up in a lathe and the sealing surfaces hand polished further. Because it is difficult to keep such a surface flat and avoid galling of aluminum the following procedure was used. A tool in the form of a thin wooden stick approximately 1/16 inch thick by 3/16 inch wide by 6 inches long was cut. One end was made square. The polishing paper was cut into strips 3/16 inch wide and several inches long. The paper was fed over the square end of the wooden tool and pressed against the sealing surface using the flexible force that could be generated by the tool. This light force helped prevent galling. A given spot on the paper was not allowed to remain in contact with the surface for more than about a second. As the paper cut it would pick up the fine aluminum chips which in turn have a tendency to gall the surface being polished. The papers used were #320, #400 (wet or dry), and #600 (wet or dry). The #320 was used to remove the concentric tool marks and chatter marks. The #400 and #600 papers were used in that order to bring the surface finish to 16 rms. When using the #400 and #600 papers the surfaces and the papers were kept wet and washed with varsol to improve the cutting of the aluminum and wash away the chips. As a final operation fine steel wool was run over the wooden tool onto the surfaces. The steel wool tended to buff the aluminum to a slightly better finish than achieved using the #600 paper.

4.2. Hemispherical Covers: The hemispherical covers were spun from 0.093 inch thick 6061-0 aluminum sheet over a wooden mandrel by Tinker Spinning Company, Elkridge, Maryland. The print (PSI F-1643) had called for a flange flatness of 0.002 T.I.R. and flange surface finishes of 16 rms. The flanges were actually received flat to 0.010 T.I.R. and had a surface finish of 32 to 64 rms. The covers were initially used with the flanges as described above, but they were eventually polished during the testing phase in a manner similar to that described for the cylindrical rings. It should be noted again that the as-received condition of the covers was annealed plus cold working due to spinning.

For assembly purposes a number was stamped adjacent to a bolt clearance hole on the flange of each cover. The same number appears adjacent to a tapped hole on one side of the cylindrical ring. The clearance and tapped holes must line up when the enclosure is assembled.

4.3. C-Ring Seals: The C-Ring seals were manufactured in accordance with PSI Drawing No. C-1645. The first operation is to flash butt weld strip stock into a band. Because of the small ratio of the strip stock thickness to width of the proposed C-Ring shown in Figure 4 satisfactory welds could not be produced using Inconel-X material. By a change to 0.015 inch thick Type 304 Stainless Steel satisfactory welds were obtained. The C-Ring actually used in the tests is shown in Figure 6. Analysis predicts approximately the same force to compress for the two seals described. The spring back should be approximately .014 for the 0.015 inch thick stainless steel C-Ring as opposed to 0.020 inch for the 0.010 inch thick Inconel-X C-Ring.

Following welding of the band, the twenty inch diameter C-Ring is formed into its basic "C" cross-section by rolling operations. Final size and shape is brought about by pressurizing the seal in a cavity between flat plates. Each seal was pressurized in a cavity to 1000 psi. The entire external surface was then hand finished with #320 paper. The sealing lines on the top and bottom of the "C" are finished to 16 rms. The silver and gold plating of the C-Rings was done by Art Metal Finishing Company, 12 L Street, S. E., Washington, 3, D. C.

5. Test Facilities

Initially proposed were an evaluation test set-up and a vacuum test set-up. Other observations were also made by bench testing and a high leakage rate test set-up which was assembled during the testing phase using the evaluation chamber.

5.1. Bench Test Set-up: (with Flange Deflection Indicator): In Figure 7 is shown the bench test set-up with a flange deflection indicator attached. Initial bench testing used this set-up without the indicator. Water plus detergent (or commercial "Snoop") was applied between the cylindrical rings and the cover flanges to check for the existence of bubble leaks. With the indicator attached, flange deflections as a function of enclosure pressure could be measured at four locations; two on each flange diametrically opposite one another.

5.2. Evaluation Test Set-up: The evaluation test set-up is shown in Figure 8. The vacuum pump was used to evacuate the enclosure prior to filling it with dry helium. The enclosure pressure could be regulated to a desired level above the evaluation chamber (steel drum) pressure followed by the detection of any leak from the enclosure. Relative leakage rates, and not actual leakage rates, could be determined with this set-up.

All connections to the drum were made with hollow rubber plugs and tubing or hose fittings. Bulkhead connectors were used to run tubing lines through the drum. The main drum cover seal was made by pouring General Electric room temperature curing RTV-615 silicone potting compound into the cover groove ¼ inch thick and allowing it to cure overnight and bond integrally with the cover.

5.3. **Vacuum Test Set-up**: The vacuum test set-up is shown in Figure 9. The external vacuum pump is used initially to evacuate the enclosure. Simultaneously the vacuum pumping system (mechanical pump and diffusion pump) evacuate the vacuum chamber. Nitrogen and helium gas is introduced into the enclosure, with knowledge of the mixture determined from the partial pressures established by observation of the dial gage. By directing the output of the vacuum pumping system to the leak detector a leakage rate is measured by detecting the amount of helium present in the exhaust gas of the vacuum chamber.

Attached to the inlet of the helium leak detector is a manifold made from three high vacuum valves, a pipe cross, pipe nipples, and an adapter plate. The manifold was made vacuum tight with glyptol paint. To the three valves on the manifold are connected a calibrated helium glass leak (7.8×10^{-7} atm cc/sec), the output of the vacuum pumping system, and the suction side of the external vacuum pump.

The system was calibrated using the following procedures. By closing the valve to the vacuum pumping system and opening the other two, a known pure helium leak is drawn through the manifold. The setting of a throttle at the inlet of the detector allows its high vacuum to draw on the manifold atmosphere. A given deflection of the leak rate meter is thus associated with the known pure helium leak.

If the calibrated glass leak valve is now closed and the output of the vacuum pumping system is drawn through the manifold, the leak rate meter will deflect to a level which is associated with the helium content of the gas leaking from the enclosure. The known calibrated glass leak rate, the proportion of helium in the enclosure gas, and the two meter readings are sufficient to calculate an enclosure leakage rate.

5.4. High Leakage Rate Test Set-up: The high leakage rate test set-up is shown in Figure 10. The vacuum pump is used to evacuate the enclosure prior to filling it with dry nitrogen. The enclosure pressure is then increased further to a positive gage pressure. The pipette is filled with water and placed in a horizontal position. The hose attached to the pipette is plugged into an opening in the steel drum. Any leakage from the enclosure is directed to the pipette and displaces water which it contains. The water is collected in a graduated cylinder. The time required to collect a given volume of water is measured on a stop watch.

Important in the use of this set-up is that the pipette be nearly horizontal such that the forces on the water are balanced. The geometry of the pipette makes it possible to have a large volume of water that is caused to flow horizontally. It is known that a pressure increase must be generated in the drum to move the water; however, this pressure was not detected on a gage.

The set-up quickly measures leakage rates over a range of enclosure pressures. Leakage rates from 0.1 to 0.5 atm cc/sec can be established in two minutes or less (a few seconds for 0.5 atm cc/sec). Leakage rates below 0.1 atm cc/sec take several minutes to establish. A series of leakage rate measurements using the leak detector is time consuming as pumping equipment must be used to pump away background helium between tests. The use of the leak detector requires that the gas mixture contain a known percentage of helium. The helium contaminates the system and if allowed to remain causes false detector readings. Of course to observe leakage rates the order of 0.01 atm cc/sec or less the sensitivity of the leak detector is required.

6. Testing

Several tests were conducted using the facilities described above. These tests involved leak checking the prototype enclosure with four types of seals: rubber O-Rings, unplated C-Rings, gold plated C-Rings, and silver plated C-Rings. The O-Rings were initially installed as enclosure seals to expedite bench leak checking of other fittings on the enclosures.

6.1. Preparation of Prototype Enclosures for Testing: All fittings on the enclosures for gas passages and electrical leads were made on the aluminum ring (see Figure 12 and PSI Drawing No. D-1644). Gas passages were provided in the rings in the form of two ¼-NPT tapped holes. Fittings in the form of adapters from $\frac{1}{4}$-NPT to hose or tubing connections could be installed or either hole could be closed by a pipe plug. All fittings were sealed using teflon tape and glyptol. Electrical leads for a 600 watt nichrome cone heater were introduced through a Conax Stainless Steel Thermocouple Gland No. TG-14-A4 ($\frac{1}{8}$" IPS). An iron-constantan thermocouple was introduced through a Conax Stainless Steel Speedwell Thermocouple Head No. SPW-MPGB-(6). Details of these fittings are shown in Figure 11.

The installation of the heater and thermocouple are shown in Figure 12. The thermocouple was placed diametrically opposite the heater. The thermocouple junction was close to the center of the enclosure. A radiation shield in the form of a tube with several holes in it was placed over the thermocouple element. The end of the tube was plugged to make the shield complete. The tube was filled with steel wool and supported over the element by two O-Rings. The purpose of this radiation shield was to assure that the thermocouple would respond only to the gas temperature in the enclosure and not to radiated heat.

6.2. Fabrication of Rubber O-Ring Seals: To set up enclosures with rubber O-Ring seals it was necessary to fabricate such seals 20 inches in diameter. Two rubber O-Rings were made. For each seal $\frac{1}{4}$ inch cross-section neoprene rubber O-Ring stock was cut to length. A butt-joint was made and bonded with Eastman 910 adhesive.

6.3. Tests using Rubber O-Ring Enclosure Seals: The test procedures and results in which rubber O-Ring enclosure seals were used are documented in Tables 1 and 2. The information in Table 1 shows that the enclosure could be made bubble tight using rubber O-Rings, that all fittings were bubble tight, and that the heater and thermocouple functioned over the temperature range of 20°C to 75°C. Upon disassembly of the covers, it was seen that the flanges had coined under the heads of the screws. For this reason brass washers which were on hand were used under the heads of the screws during assembly of Enclosure B. Also the torque wrench was acquired and used to control and limit the screw force during the second assembly of Enclosure B. Enclosure B with the rubber O-Rings installed was tested using the evaluation chamber and leak detector to check the test procedures and test hardware.

Table I

Enclosure A (sides 1 and 2)
with Rubber O-Ring Seals

1. Rubber O-Rings installed in grooves of cylindrical ring.
2. Assembled hemispherical covers.
   2a. #5-40 Allen head cap screws used.
   2b. Torqued lightly by hand.
3. Atmospheric air plus 13 psig helium applied to enclosure.
   3a. Water plus detergent used to check for bubble leaks at seals and fittings.
   3b. Fittings found to be bubble tight; some bubble leaks

found around circumferences of seals.

3c. Bolts near bubble leaks tightened until leaks stopped.

4. Electrical power run to cone heater.

4a. Current controlled through 2 kva auto transformer.

4b. Pressure buildup inside enclosure due to heating of the gas bled off.

4c. Thermocouple monitored over temperature range of 20°C to 75°C by an API Model 503 pyrometer having a 2% accuracy.

Table 2

Enclosure B (sides 3 and 4)
with Rubber O-Ring Seals

1. Rubber O-Rings installed in grooves of cylindrical ring.
2. Assembled hemispherical covers.

2a. #5-40 Allen head cap screws and brass washers used.

2b. All screws torqued to 5 in-lb (600 lb. axial force/screw).

3. Atmospheric air plus 13 psig helium applied to enclosure.

3a. Water plus detergent used to check for bubble leaks at seals and fittings.

3b. Fittings found to be bubble tight; some bubble leaks found around circumferences of seals.

4. Electrical power run to cone heater.

4a. Current controlled through 2 kva auto transformer.

4b. Pressure buildup inside enclosure due to heating of the gas bled off.

4c. Thermocouple monitored over temperature range of 20°C to 75°C by the API 503 pyrometer.

5. Enclosure placed in evaluation chamber.

5a. Chamber connected to external leak detector manifold.

5b. Enclosure evacuated by mechanical vacuum pump.

5c. Chamber partially evacuated to -2.5 in hg. by mechanical vacuum pump.

5d. Leak detector pressure not recorded.

5e. Leak detector meter reading: 0.100.
Attenuator dial at 300X
Therefore, leak rate reading = 30 divisions.

5f. Enclosure pressure increased to 7 psig helium.

5g. Leak detector throttle valve set for pressure of 0.01 micron.

5h. Leak detector meter reading: 0.217
Attenuator dial at 300 X
Therefore, leak rate reading = 65 divisions.

5i. External leak detector manifold exhausted.

5j. Calibrated glass leak introduced into manifold.

5k. Chamber pressure maintained at -2.5 in hg.

5l. Leak detector throttle valve unchanged; leak detector pressure remained 0.01 micron.

5m. Leak detector meter reading: 0.117
Attenuator dial at 300X
Therefore, calibration leak rate reading = 35 divisions.

6.4. Tests using Unplated C-Ring Seals: The test procedures and results in which unplated C-Ring enclosure seals were used are documented in Table 3. Removal of the hemispherical covers revealed that the sealing lines were not complete on the flange and cavity sealing surfaces. These discontinuities were in the form of concentric leak paths between the high portions of adjacent tool marks that were not continuous themselves. The C-Rings had made metal-to-metal contact with these high portions. The bubble leakages and leak detector readings were in agreement as the unplated seals had higher leakage rates than the rubber O-Rings as indicated by both types of observation.

Table 3

Enclosure A (sides 1 and 2) with
Unplated Metal C-Rings

1. Unplated C-Rings installed in grooves of cylindrical ring.
2. Hemispherical covers assembled.
   2a. No. 5-40 Allen head cap screws and No. 4 stainless steel washers used.
   2b. All screws torqued to 5 in-lb (600 lb. axial force/screw).
3. Atmospheric air plus 13 psig helium applied to enclosure; bubble leakage large as determined from application of water plus detergent.
4. Enclosure placed in evaluation chamber.
   4a. Chamber connected to external leak detector manifold.
   4b. Enclosure evacuated by mechanical vacuum pump.
   4c. Chamber partially evacuated to -2.5 in Hg.
   4d. Leak detector pressure: 0.02 micron.
   4e. Leak detector meter reading: 0.117
   Attenuator dial at 300X
   Therefore, leak rate reading = 35 divisions.
   4f. Enclosure pressure increased to 3 psig helium.
   4g. Leak detector throttle valve set for pressure of 0.005 micron.
   4h. Leak detector meter reading: 0.767
   Attenuator dial at 300X
   Therefore, leak rate reading = 230 divisions.
   4i. External leak detector manifold exhausted.
   4j. Calibrated glass leak introduced into manifold.
   4k. Chamber pressure maintained at -2.5 in Hg.
   4l. Leak detector throttle valve unchanged; leak detector pressure remained 0.005 micron.
   4m. Leak detector meter reading: 0.093
   Attenuator dial at 300X
   Therefore, calibration leak rate reading = 28 divisions.

6.5. Tests using Gold Plated C-Ring Seals: The tests using the gold plated C-Rings are documented in Table 4. The flange deflection data (Figure 13 and Table 6 in the Appendix) obtained for Enclosure A were felt to be representative of both enclosures.

Table 4

Enclosure A (sides 1 and 2)
with Gold-Plated C-Rings

1. C-Rings and sealing surfaces cleaned with acetone and lint-free paper.
2. Gold plated C-Rings installed in grooves of cylindrical ring.
3. Hemispherical covers assembled.
   3a. No. 5-40 Allen head cap screws and No. 4 steel washers used.
   3b. All screws torqued to 5 in-lb (600 lb. axial force/screw)
4. Atmospheric air plus 13 psig helium applied to enclosure; bubble leakage using water plus detergent observed to be smaller than when using unplated C-Rings.
5. Enclosure vented to atmosphere.
6. Electrical power run to cone heater.
   6a. Enclosure held at 70°C for 2 hours.
   6b. The procedure of step 6a expedites the plastic flowing of the plating.
7. Enclosure set up on bench (at room temperature).
   7a. Enclosure evacuated by mechanical vacuum pump.
   7b. Dry nitrogen introduced into enclosure at 10 psig.
   7c. Enclosure not bubble tight.
   7d. Enclosure pressure indicated on dial gage was observed to drop continuously.
   7e. Nitrogen felt rushing by hand at two points on side 2. These points were marked on the enclosure.
8. Enclosure vented to atmosphere.
9. Indicator attached as shown in Figure 7.
   9a. Indicator stem placed over sealing line behind screw.
   9b. Enclosure air pressure increased in 3 psi increments to 12 psig and flange deflections recorded.
   9c. Indicator stem moved along sealing line between the screw above and an adjacent screw.
   9d. Step 9b repeated.
   9e. Indicator stem moved along sealing line to position behind the screw adjacent to first screw.
   9f. Step 9b repeated.
   9g. Indicator moved to a location 180° from first location and steps 9a through 9f repeated.
   9h. Indicator moved to a location opposite location of step 9g on other flange; steps 9a through 9f repeated.
   9i. Indicator moved to a location 180° from location of step 9h; steps 9a through 9f repeated.
   9j. Results of steps 9 plotted in Figure 13.
10. Hemispherical cover on side 2 removed.
   10a. Sealing line on flange observed to be a band of radial "scrub" marks.
   10b. Sealing line not continuous at two points discussed in step 7e.

11. C-Ring removed from cavity.

11a. Sealing line observed to be a band of radial "scrub" marks less intense than on flange.

11b. Seal and cavity dimensions recorded in Table 7 in the Appendix.

6.6. Tests using Silver Plated C-Ring Seals: The tests using silver plated C-Ring seals are documented in Table 5. The evaluation test set-up was not used in testing the plated seals as the observations of bubble leaks readily indicated that the silver plated seals had the smallest leakage of the metal seals. Upon completion of the tests using the silver plated seals, the cover on side 3 was removed and the C-Rings and sealing surfaces inspected. It was observed that on the C-Ring surface near several bolts were areas which appeared discolored or tarnished. These areas were not on the sealing line and would not have affected seal performance. During bubble leak checking of the enclosure detergent collected behind the bolts and too rapid heating of the enclosure to 70°C tarnished the silver plating.

Table 5

Enclosure B (sides 3 and 4) with
Silver-plated Metal C-Rings

1. C-Rings and sealing surfaces cleaned with acetone and lint-free paper.
2. Silver plated C-Rings installed in grooves of cylindrical ring.
3. Hemispherical covers assembled.

3a. No. 5-40 Allen head cap screws and No. 4 stainless steel washers used.

3b. All screws torqued to 5 in-lb (600 lb. axial force/screw).

4. Atmospheric air plus 13 psig helium applied to enclosure; small bubble leakage observed using water plus detergent.
5. Enclosure vented to atmosphere.
6. Electrical power run to cone heater.

6a. Enclosure held at 70°C for 2 hours.

6b. The procedure of step 6a expedites the plastic flow of the silver plating.

7. Enclosure set up on bench (at room temperature).

7a. Enclosure evacuated by mechanical vacuum pump.

7b. Dry nitrogen introduced into enclosure at 10 psig.

7c. Enclosure not bubble tight as observed by using water plus detergent; however, leak was small.

7d. A decrease in the enclosure pressure, as indicated on a dial gage, was not observed over a two minute period.

8. Enclosure vented to atmosphere.
9. Enclosure set up on vacuum chamber base plate (24 hours after steps 7 and 8).

9a. Current run to cone heater through auto transformer; pyrometer indicated increasing temperature in response to thermocouple.

9b. Enclosure evacuated by mechanical vacuum pump.

9c. Dry nitrogen introduced into enclosure began to develop bubble leaks at 5 psig as indicated by commercial "Snoop".

9d. Dry nitrogen pressure increased to 10 psig; bubble leaks increased but were observed to be smaller than in step 7c.

9e. Enclosure vented to atmosphere.

10. Large stainless steel bell jar of vacuum chamber placed in position.

10a. Evacuation of enclosure begun using mechanical vacuum pump.

10b. Evacuation of vacuum chamber begun using vacuum pumping system.

10c. Vacuum pumps run overnight.

11. Chamber pressure observed to be 0.01 micron (10^{-5} torr) on discharge vacuum gage.

12. Enclosure pressure observed to be -30 inches of mercury on bourdon tube dial vacuum gage.

13. Leak rate test begun.

13a. Output of vacuum pumping system directed to external leak detector manifold.

13b. Suction side of external mechanical pump connected to manifold.

13c. Enclosure pressure increased to -21 in Hg (9 in Hg abs). Gas mixture: 19 parts N_2, 1 part He.

13d. Chamber pressure observed to increase to 9 microns (9×10^{-3} torr).

13e. Throttle valve set for leak detector pressure of 0.17 micron.

13f. Leak detector meter reading: 0.433.
Attenuator dial at 300X
Therefore, leak rate reading = 130 divisions.

13g. Output of vacuum pumping system excluded from external leak detector manifold.

13h. Calibrated pure helium glass leak introduced into manifold.

13i. Throttle valve in same position as step 13e.

13j. Leak detector pressure observed to be 0.01 micron.

13k. Leak detector meter reading: 0.14
Attenuator dial at 100X
Therefore, calibration leak rate reading = 14 divisions.

14. Chamber and enclosure again evacuated overnight.

15. Chamber pressure observed to be 0.005 micron (5×10^{-6} torr) on discharge vacuum gage.

16. Enclosure pressure observed to be -30 in Hg on dial gage.

17. Leak rate test begun.

17a. Output of vacuum pumping system directed to external leak detector manifold.

17b. Suction side of external mechanical pump connected to manifold.

17c. Enclosure pressure increased to -15 in Hg (15 in Hg abs). Gas mixture: 29 parts N_2, 1 part He.

17d. Chamber pressure observed to be 20 microns (20×10^{-3} torr).

17e. Throttle valve set for leak detector pressure of 0.08 micron.

17f. Leak detector meter reading: 0.26
Attenuator dial at 100X
Therefore, leak rate reading = 26 divisions.

17g. Output of vacuum pumping system excluded from external leak detector manifold.

17h. Calibrated pure helium glass leak introduced into manifold.

17i. Throttle valve in same position as step 17e.

17j. Leak detector pressure: not recorded.

17k. Leak detector meter reading: 0.233
Attenuator dial at 3X
Therefore, calibration leak rate reading = 0.7 divisions.

18. Calibrated pure helium glass leak excluded from manifold.

19. Output of vacuum pumping system directed to manifold.

20. Leak rate test begun.

20a. Enclosure pressure raised to -10 in Hg vacuum (20 in Hg abs). Gas mixture: 39 parts N_2, 1 part He.

20b. Chamber pressure observed to be greater than 20 micron (full scale on discharge vacuum gage).

20c. Pressure between mechanical and diffusion pumps of vacuum pumping system observed to be just under full scale (2000 micron) on Pirani vacuum gage. Therefore, chamber pressure was less than 2000 microns.

20d. Throttle valve set for leak detector pressure of 0.025 micron.

20e. Leak detector meter reading: 1 (tending off full scale)

Attenuator dial at 300X
Therefore, leak rate reading = 300 divisions.

20f. Output of vacuum pumping system excluded from external leak detector manifold.

20g. Calibrated pure helium glass leak introduced into manifold.

20h. Throttle valve in same position as Step 20d.

20i. Leak detector pressure: not recorded.

20j. Leak detector meter reading: 0.02
Attenuator dial at 1X
Therefore, calibration leak rate reading = 0.02 divisions.

21. Chamber and enclosure slowly vented to atmosphere.

22. Bell jar removed from vacuum chamber base plate.

23. Enclosure placed in evaluation chamber in high leakage rate set-up (Figure 10).

24. Enclosure evacuated using external mechanical vacuum pump.

25. Enclosure filled with one atmosphere of dry nitrogen.

26. Leakage rate test run.

26a. Enclosure pressure increased in 1 psi increments to 15 psig (nitrogen); dropped to 5 psig; dropped to 0 psig.

26b. Water displaced from pipette by enclosure leakage gas collected in graduated cylinder (determined for each 1 psi increment).

26c. Time to displace a given quantity of water measured using a stop watch.

27. Enclosure removed from chamber.

28. Hemispherical cover on side 3 removed and replaced.

29. Steps 23 through 27 repeated.

30. Hemispherical cover on side 3 removed.
    30a. Sealing line on flange observed to be continuous.
    30b. Sealing line in the form of a band of light radial "scrub" marks.

31. C-Ring removed from cavity.
    31a. Sealing line on ring observed to be continuous.
    31b. Sealing line in the form of a band of very light radial "scrub" marks.

32. Enclosure reassembled.

7. Conclusions

Because of the number of variables in the design of a twenty-inch diameter metal enclosure seal, the limited test results presented here are not sufficient to predict which platings and coatings (if any) should be used with a metal C-Ring for a zero leakage seal. These results do suggest certain design and procedural changes that should result in a minimum, if not a zero, leakage rate using a C-Ring, probably silver-plated.

The three points plotted in Figure 14 are of the leakage rates of the silver-plated seals as a function of the enclosure pressure. These data are from tests in the vacuum chamber. These data indicate that initially at lower pressure differentials the seal was quite effective. As the pressure was increased the seal lost its effectiveness. Figure 14 is a semi-logarithmic plot and, therefore, the rate of increase of the leakage from point 2 to point 3 is much greater than from point 1 to point 2. From step 9c of Table 5 we see that the bubble leakage just prior to the vacuum tests was not observed until the dry nitrogen pressure reached 5 psig. The increase of this pressure to 10 psig resulted in a steady increase in the bubble leakage. Thus the bubble leakage tests and vacuum tests appear to be in agreement.

Figure 15 is a plot of the tests run in the high leakage rate test set-up. The first test (curve'A') does not indicate a leak rate in response to the enclosure pressure of the same form as the bubble leak tests and vacuum tests (the vacuum tests points 1, 2, and 3 are also plotted in Figure 15). Point 3, however, does agree closely with the data of the high leakage tests at approximately 9 to 10 psi. These data suggest that the seal lost its effectiveness during the vacuum tests and did not completely recover.

The following observations indicate the initial sealing capability of the silver-plated C-Ring:

(1) The lack of bubble leakage until 5 psig dry nitrogen was reached prior to vacuum testing, (2) the low leakage measured at point 1 during vacuum testing,& (3) the fact that at 1 psig during the first high leakage test no leak was detected. One concludes that the soft silver-plating had flowed into surface irregularities both during the heating of the enclosure and during the period overnight just prior to vacuum testing. The heating process in particular can cause a weak bonding of the sealing surface to the C-Ring through the silver. During the vacuum testing these bonds apparently broke down due to the large flange deflections. The mating surfaces between C-Rings and sealing surfaces still lined up, though, and at near zero positive enclosure pressures, the flange deflections were not great enough to develop a detectible leak. Once the hemispherical cover was removed the bonding was completely broken down. Since the cover could not be replaced with perfect alignment of the mating surfaces, an increased leakage was observed as indicated by curves B and C of Figure 15.

The decrease in the leakage rate at higher pressures for curves A and B demonstrate that the flexible C-Ring responds to the internal pressure and follows the flange deflections. The curves, A, B and C also suggest some analysis which explains and helps verify the above comment.

Over the range of pressures which the high leakage tests were run (14.7 psia ambient pressure; 14.7 to 29.7 psia enclosure pressure) the following relation can be shown to be approximately true for the flow of a compressible fluid through a venturi or orifice.

$$Q = K\sqrt{P_2 - P_1}$$

Q: Volume flow rate

P_2: Throat or minimum jet area pressure

P_1: Inlet pressure

If we now plot $\sqrt{\Delta p}$ against Δp up to 15 psig in Figure 16 we see that the curves A and B of Figure 15 are not of the same form as $\sqrt{\Delta p}$ vs Δp whereas curve C is. The assumption here is that the enclosure seal leakage paths approximate a series of orifices or venturis. Considering the throat or minimum jet area pressure to be the ambient pressure no doubt leads to some error, particularly at low enclosure pressures. The results do suggest that the C-Ring closes up the leakage path size at high pressures. Also the shape of curve C suggests that the removal of one cover caused misalignment of surface irregularities which resulted in the addition of constant leakage paths during the second high leakage test. Further analysis is suggested by the above results. Given the measured flow rates and the pressures we can develop the following equation:

$$A = \frac{1.5 \times 10^{-5}\, Q}{\sqrt{P_a - P_e}}$$

A: Area of equivalent orifice (in^2)

Q: Measured volume flow rate (atm cc/sec)

P_a: Ambient pressure (psia)

P_e: Enclosure pressure (psia)

Over the pressure range of these tests, the above equation is approximately true. Using the results obtained from this equation, we can plot Figure 17. Here we see more explicitly the decrease in leakage path with increasing pressure and the addition of a constant leakage path upon the removal of a hemispherical cover. The calculated magnitudes of the leakage path can at best be only reasonable approximations to those that actually exist, but these numbers can give insight into the problems of imperfect surface finishes.

Previous experience has shown that the surfaces finishes prior to testing should have been sufficient for this sealing application. The radial "scrub" marks developed during testing caused a deterioration of these surfaces. The large axial flange deflections, Figure 13, have an associated relative radial motion between flange and C-Ring. On the aluminum a protective aluminum oxide surface forms. The silver-plating, being softer than the aluminum, picks up this oxidation and abrades the aluminum surface during the relative motions between C-Ring and flange.

This result along with the flange deflection data of Figure 13 suggest that flange deflections should be kept below 0.003 inch. The original analysis predicted that with a 15 psi pressure differential applied across the enclosure the flange deflections would be from zero to less than 0.003 inch, the variations being due to the one inch bolt spacing. The measured deflections indicate, however, that the variations would be 0.0045 to 0.0075 inch, with variations due to the one inch bolt spacing being less than 0.001 inch. The fact that the flange deflections overall were larger than expected and that there was variation around the enclosure can be attributed to localized yielding of the soft aluminum flanges under the bolt heads and washers and a different response of the structure to the pressure loading than expected. One recommendation would be to add rings between the bolt heads and flanges to make the flange structure more rigid. These rings should be the same order of thickness as the existing flange and have approximately the same transverse dimensions as the flange. A ring of sufficient thickness should also make a reduction in the number of bolts feasible. A bolt reduction should not be attempted, however, until a satisfactory seal is obtained with the present number of bolts.

The use of "Alodine" (amorphous chromate) coatings on the aluminum would eliminate the oxidation of the surfaces. The "Alodine" surface should also be representative of a beryllium surface if that material were used for the enclosure rather than aluminum.

Thicker platings should also be attempted on the C-Rings. If a satisfactory thick plating is achieved, the soft silver more readily flows into any irregularities in the mating surfaces. The addition of a still softer indium overlay should result in still further improvement of the seal performance. The fact that the seal effectiveness decreased markedly upon increase in the enclosure pressure in the vacuum chamber is attributed to excessive flange deflections, and to some extent to the formation of the radial "scrub" marks. The fact that the existing seal does not have the reuseability characteristics expected as indicated by Figure 15 is attributed to the radial "scrub" marks. Although the cover was replaced in the same orientation as it had been prior to its removal, the deformations in the plating could not be expected to line up precisely with those in the flanges and grooves. Elimination of the radial "scrub" marks would afford the smooth sealing surfaces a better opportunity to re-seal. A technique for precompressing the C-Ring prior to actual service in the enclosure should be studied. Axial deflections of the "c" cross section of the C-Ring have corresponding radial movements. By precompressing the C-Ring the tendency to form radial marks in the aluminum (or "Alodine") sealing surface would be decreased.

Although the required sealing problem is difficult, the results thus far obtained indicate that the problem can be solved using metal seals and ultimately obtain zero leakage. Each seal has a circumference of approximately 60 inches with two sealing surfaces. Statistically it is difficult to obtain complete metal-to-metal contact on all of the sealing surfaces. However, inspection of the surfaces using the silver plated seals indicated that the sealing lines were complete. The main problems now are to maintain in service the sealing surfaces as processed and to decrease flange deflections.

8. Recommendations

If further work is to be done in developing metallic enclosure seals, Pressure Science Incorporated recommends that use be made of the existing prototype hardware. Additional manufacturing would be required only for flange-stiffening rings, sealing surface rework, C-Ring rework or manufacture of new seals, and the applications of platings and "Alodine" coatings. Engineering testing would consist of the use of the already developed bench testing procedures, the high leakage set-up (Figure 10), the evaluation set-up (Figure 8), modified to obtain quantitative data, and the vacuum test set-up (Figure 9). The suggested design and procedural changes to reduce flange deflections and maintain as-processed sealing surface finishes would be evaluated using these set-ups.

APPENDIX

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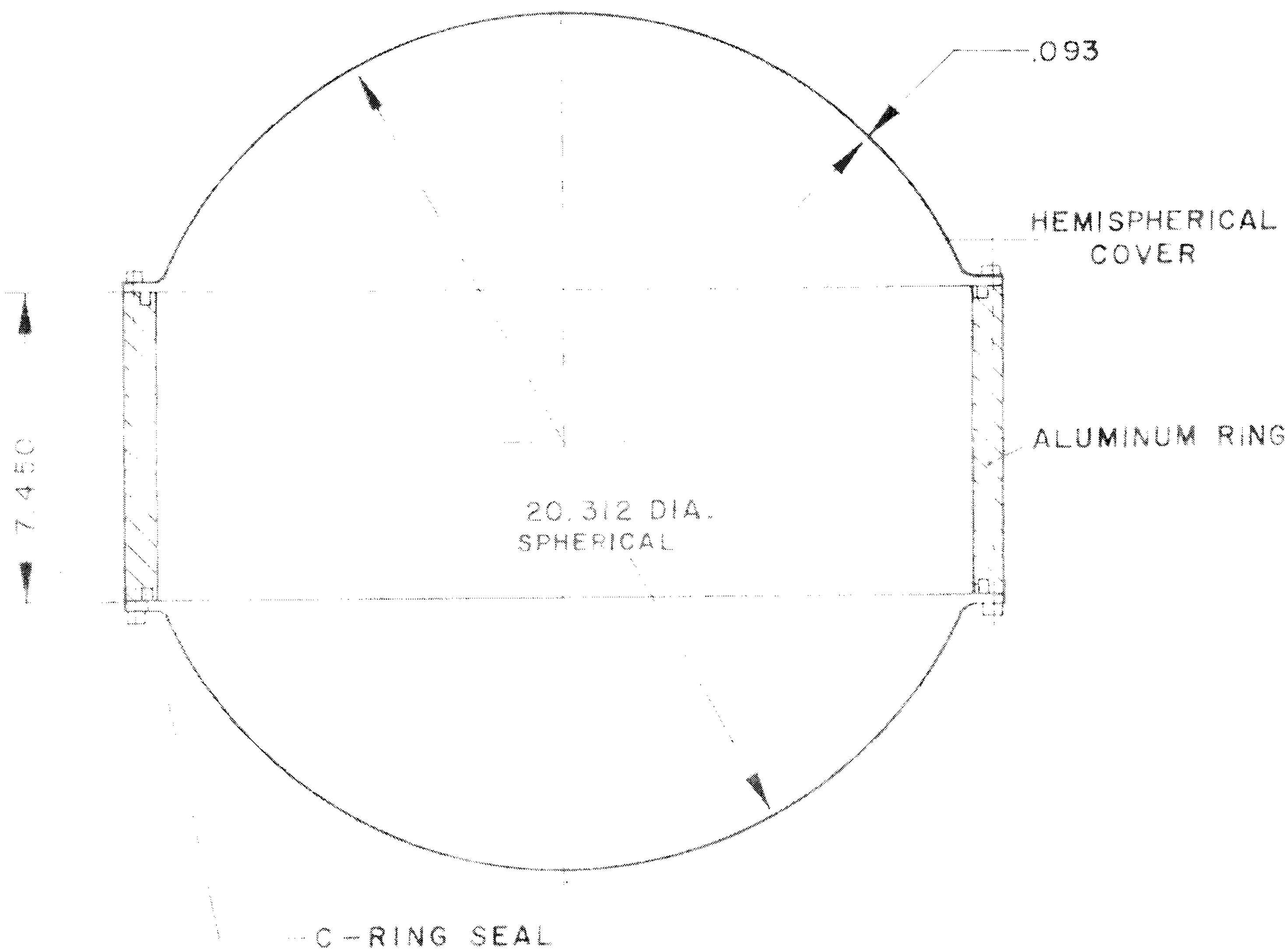

PROTOTYPE ENCLOSURE WITH C-RING SEALS INSTALLED

FIGURE 1

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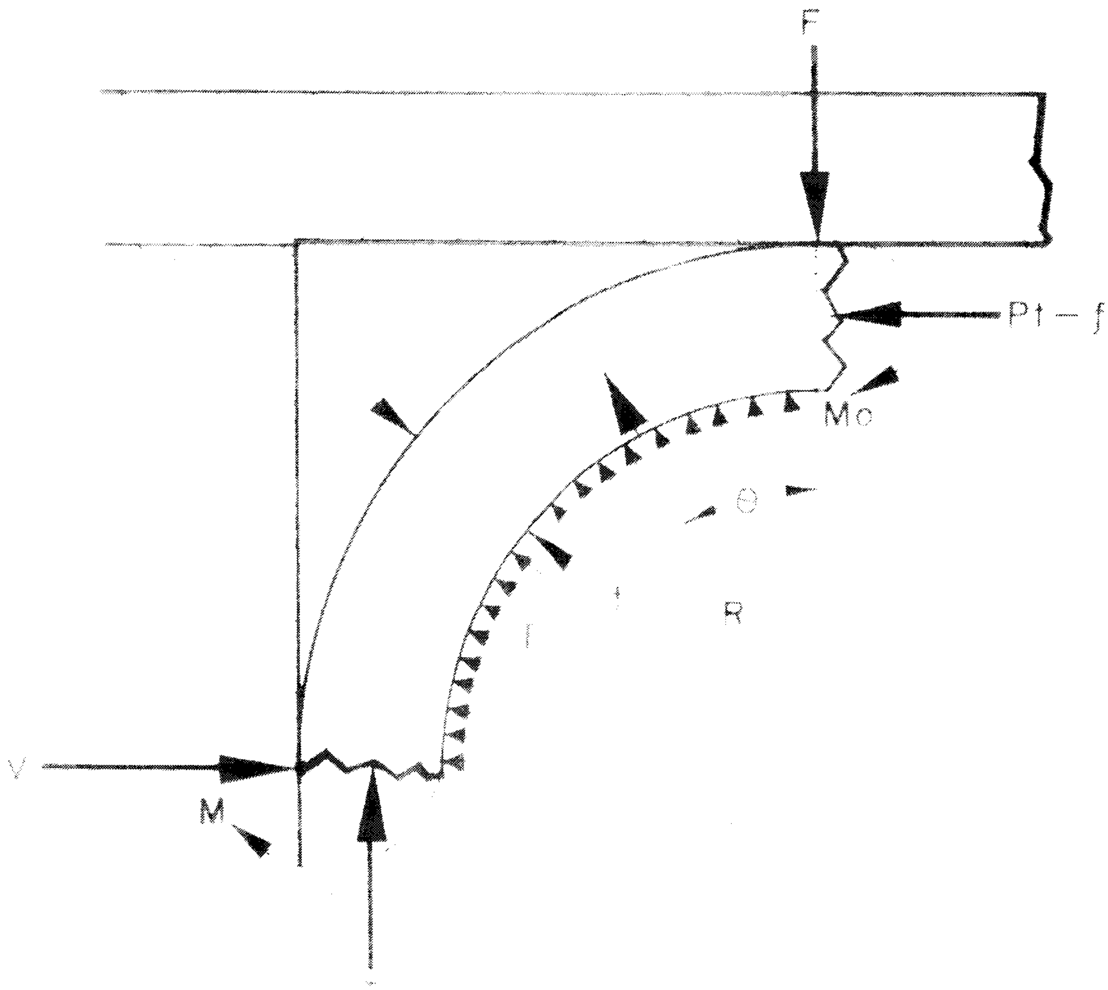

ANALYSIS SKETCH

FIGURE 2

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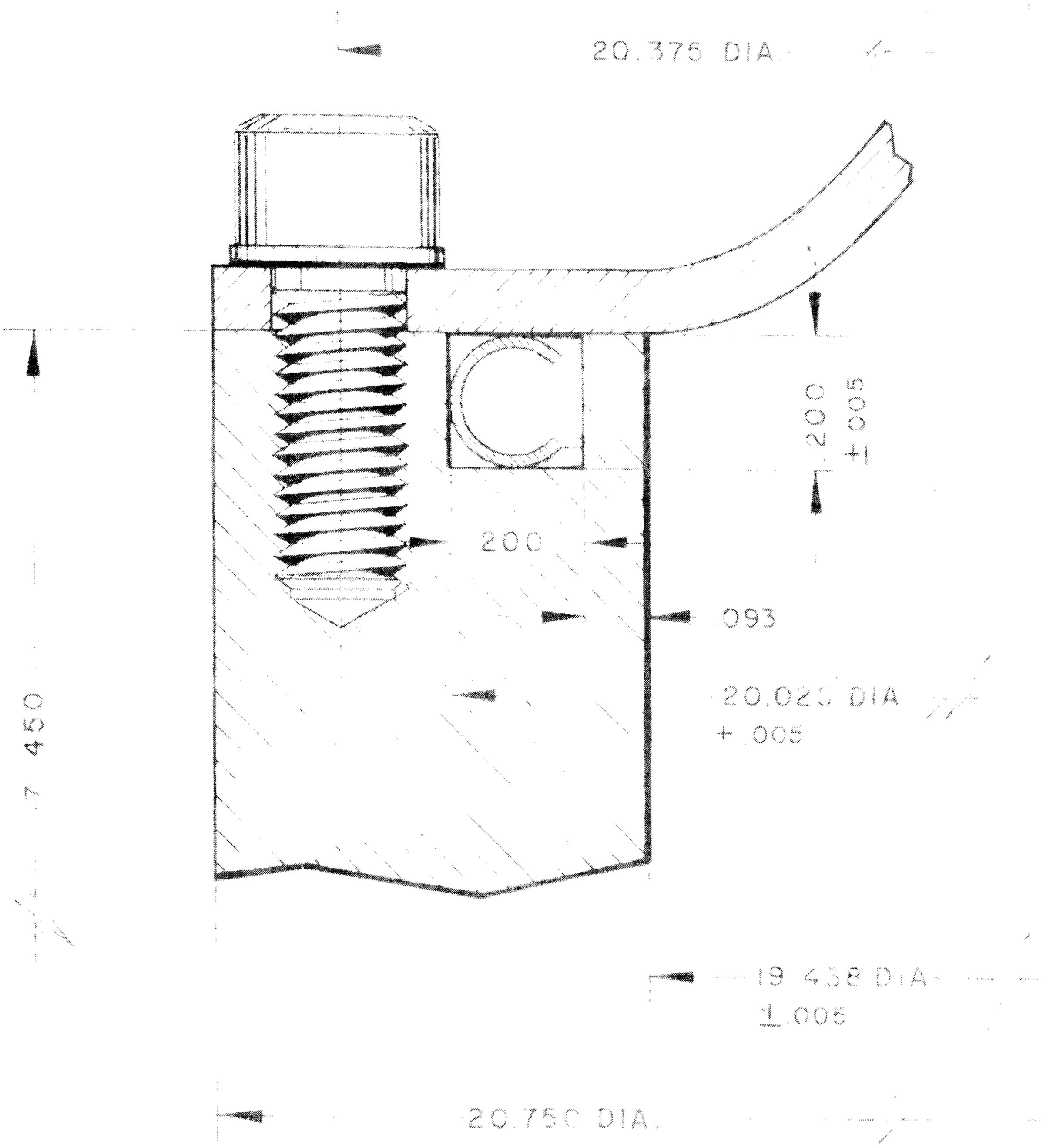

FIGURE

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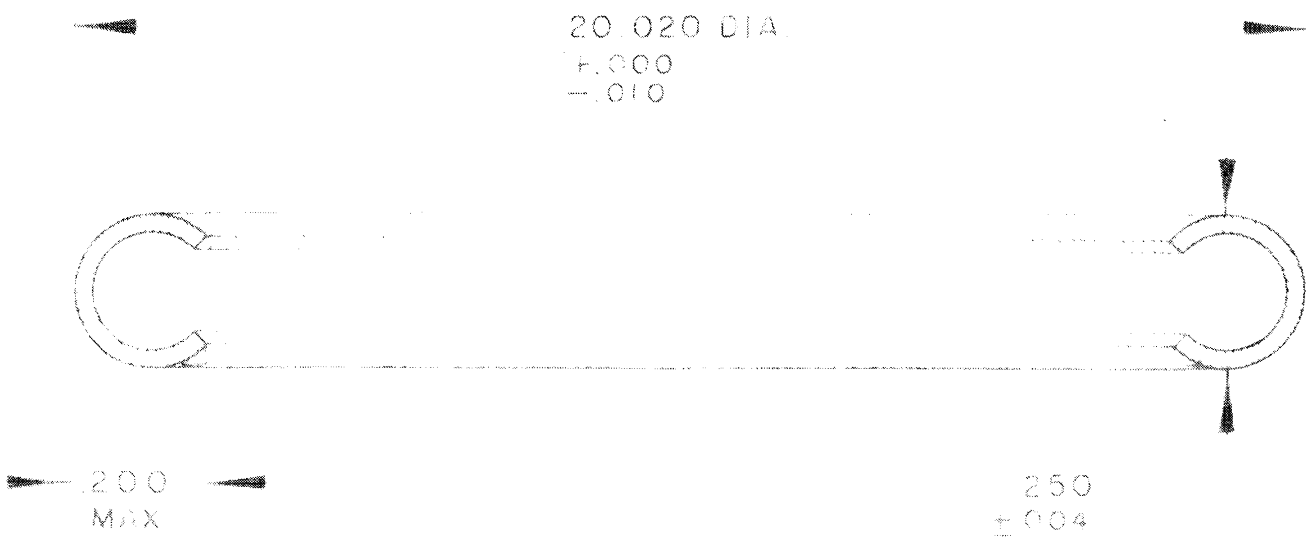

MATERIAL: INCONEL-X, SILVER OR GOLD PLATED

FORCE TO COMPRESS 100 lbs/LINEAR INCH.

PROPOSED C-RING SEAL

FIGURE 4

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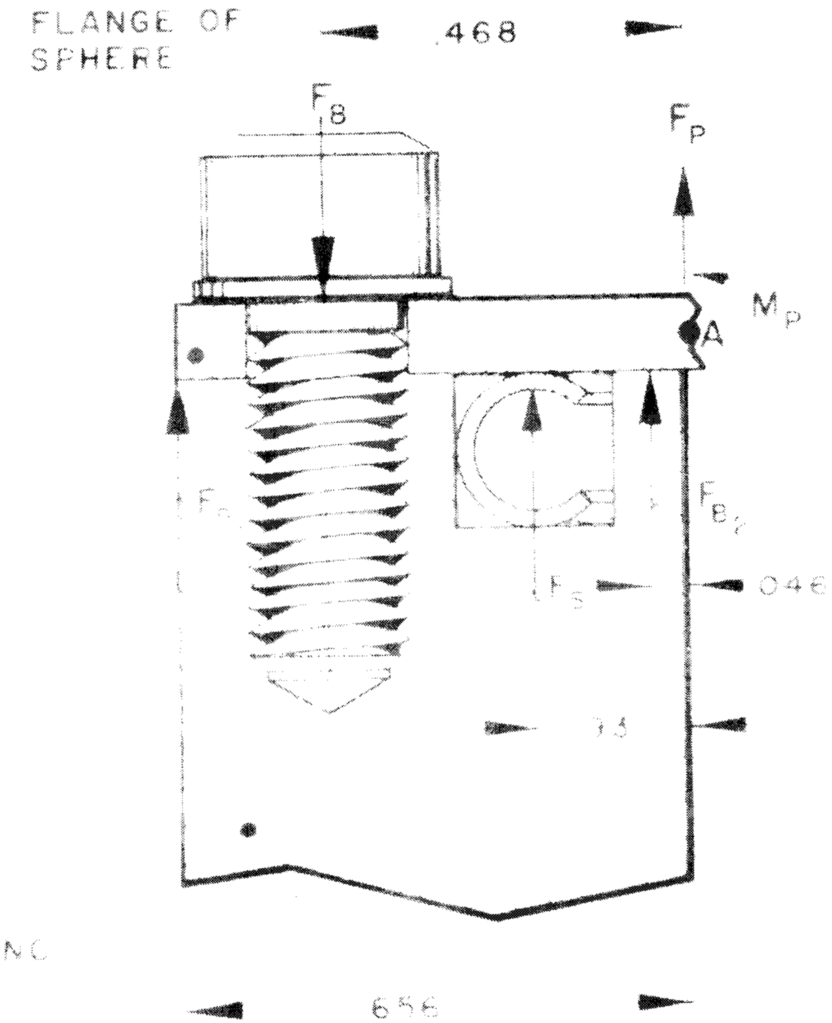

F_B = BOLT FORCE

F_{B_1} = BEARING SURFACE FORCE.

F_{B_2} = BEARING SURFACE FORCE.

F_S = SEALING FORCE

F_P = PRESSURE GENERATED FORCE

M_P = BENDING MOMENT GENERATED BY PRESSURE.

SEALING SURFACE DEFLECTION NOMENCLATURE

FIGURE 5

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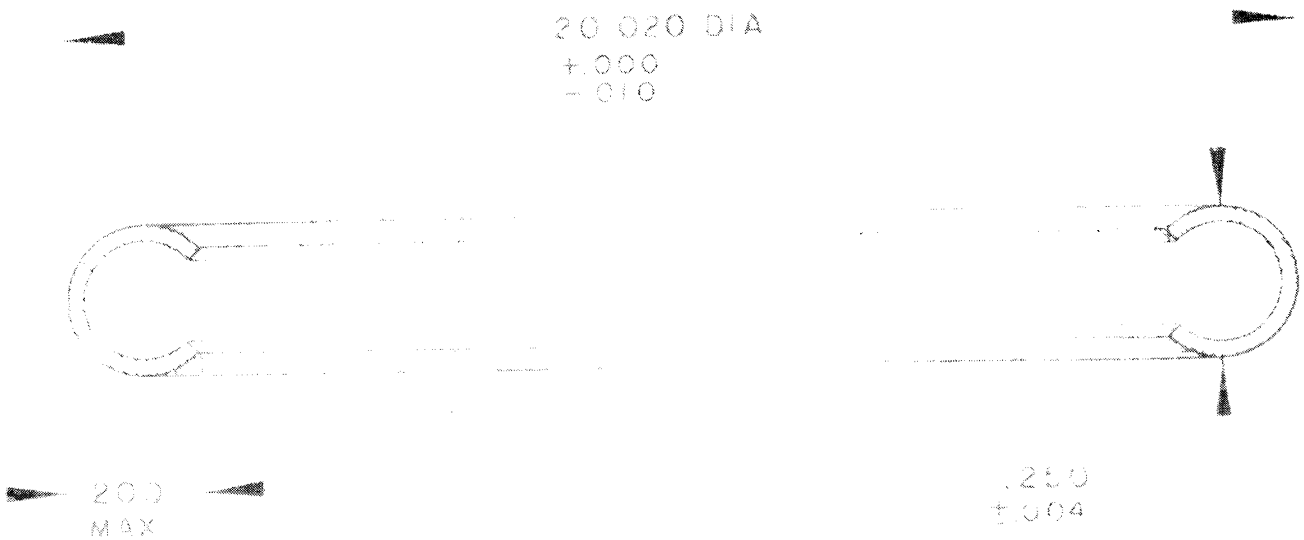
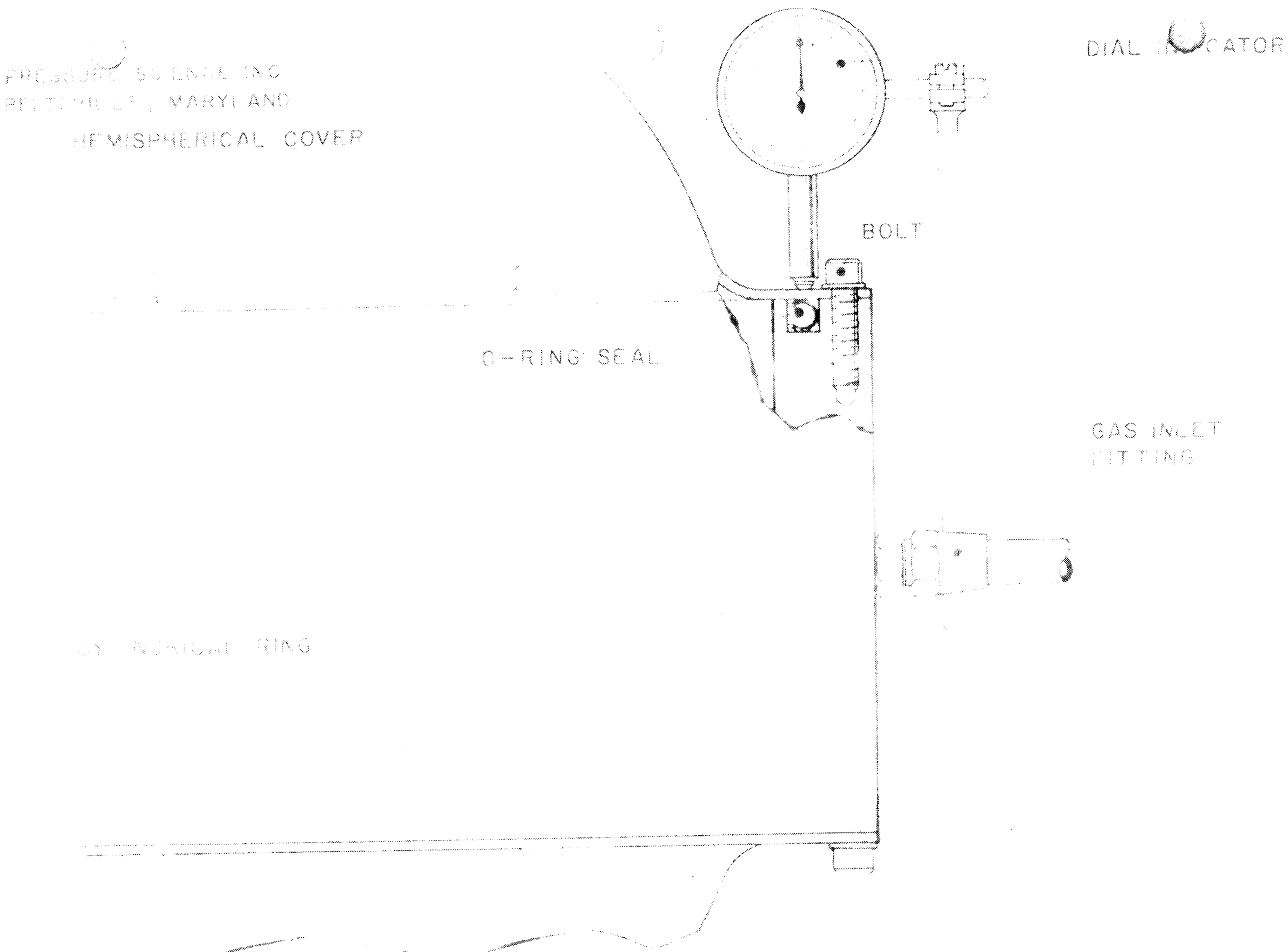


MATERIAL TYPE 304 STAINLESS STEEL, SILVER PLATED.
FORCE TO COMPRESS 100lbs/LINEAR INCH.

C-RING ENCLOSURE SEAL

FIGURE 6



BENCH TEST SET-UP (WITH DIAL INDICATOR ATTACHED)

FIGURE 7

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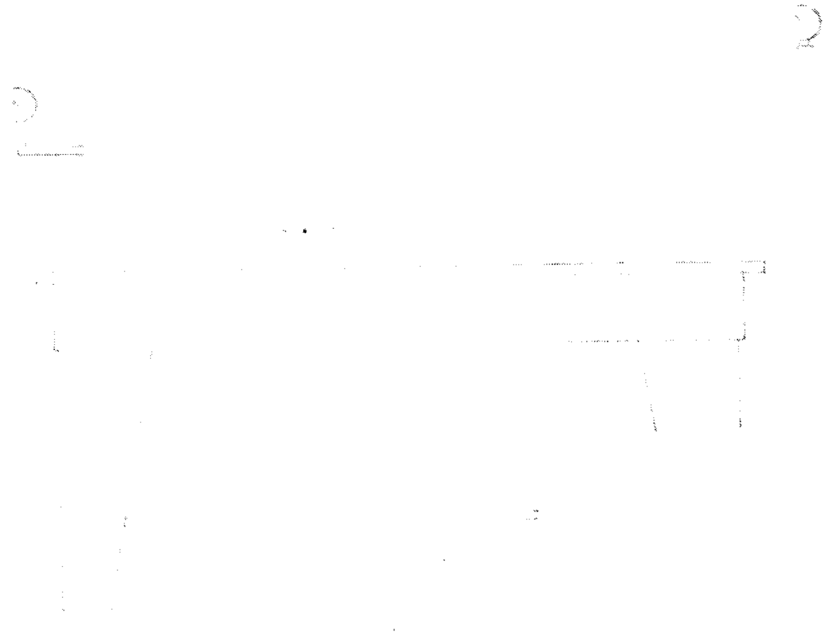

EVALUATION TEST SETUP

FIGURE 8

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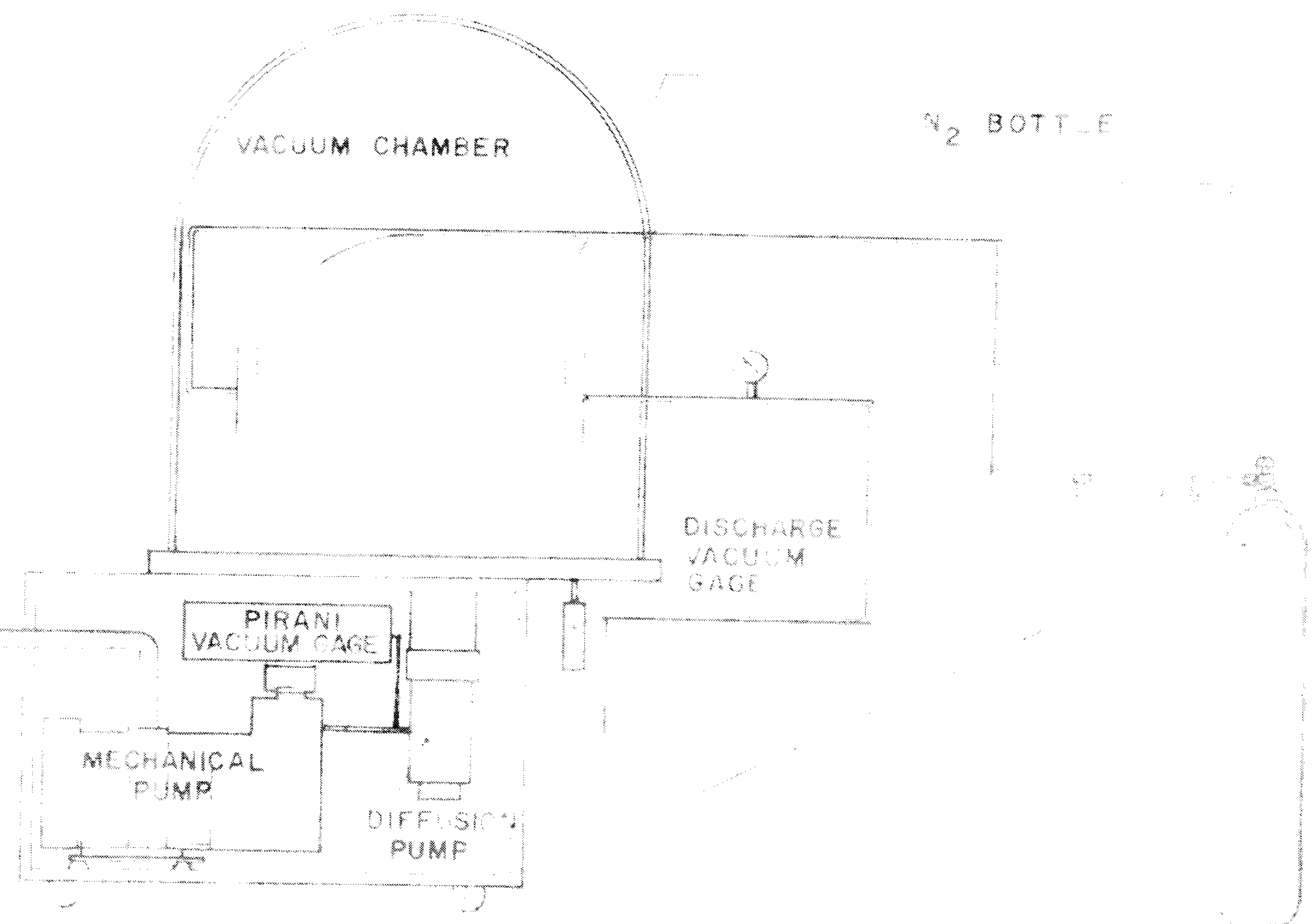
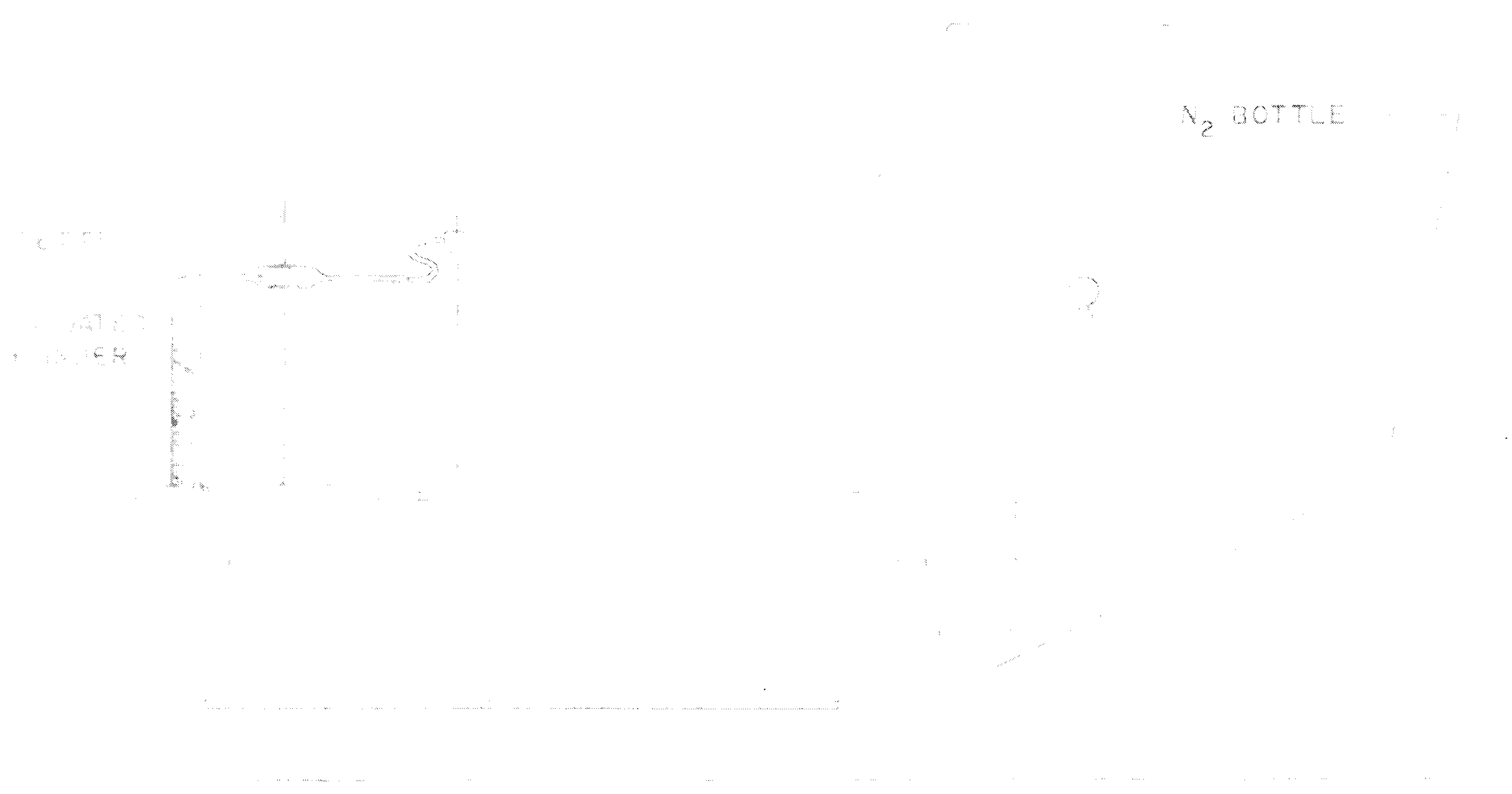


VACUUM TEST SET UP

FIGURE 9



HIGH LEAKAGE RATE TEST SET-UP

FIGURE 10

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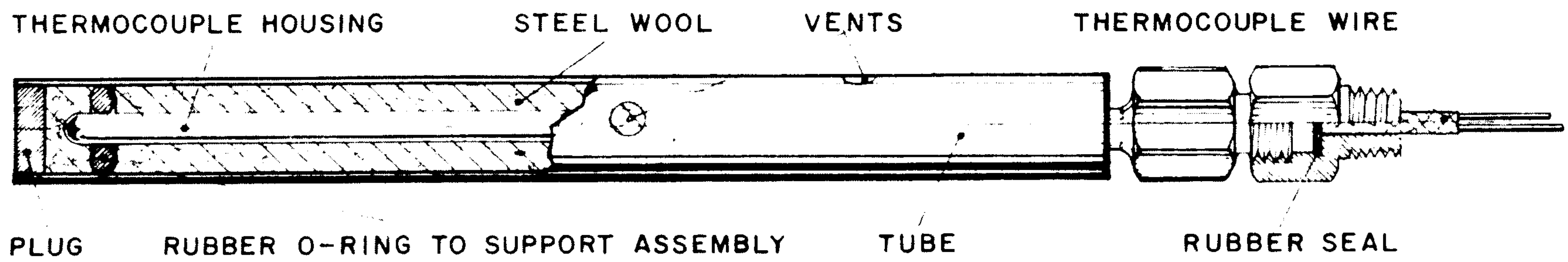
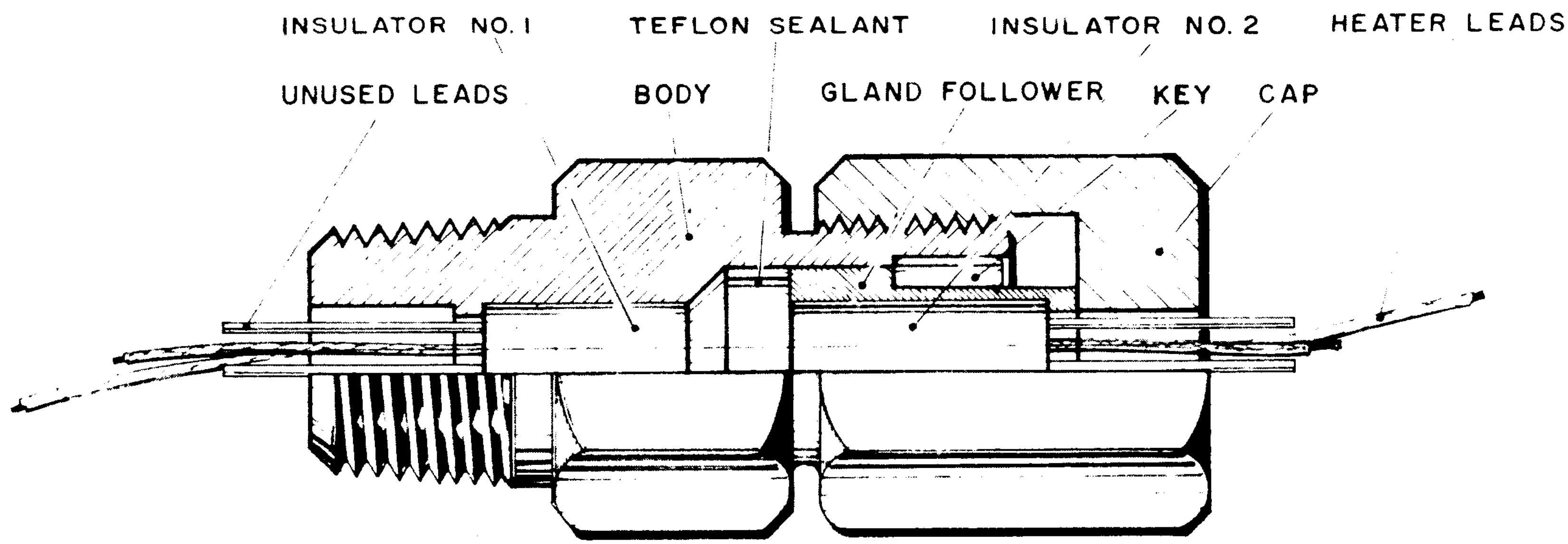


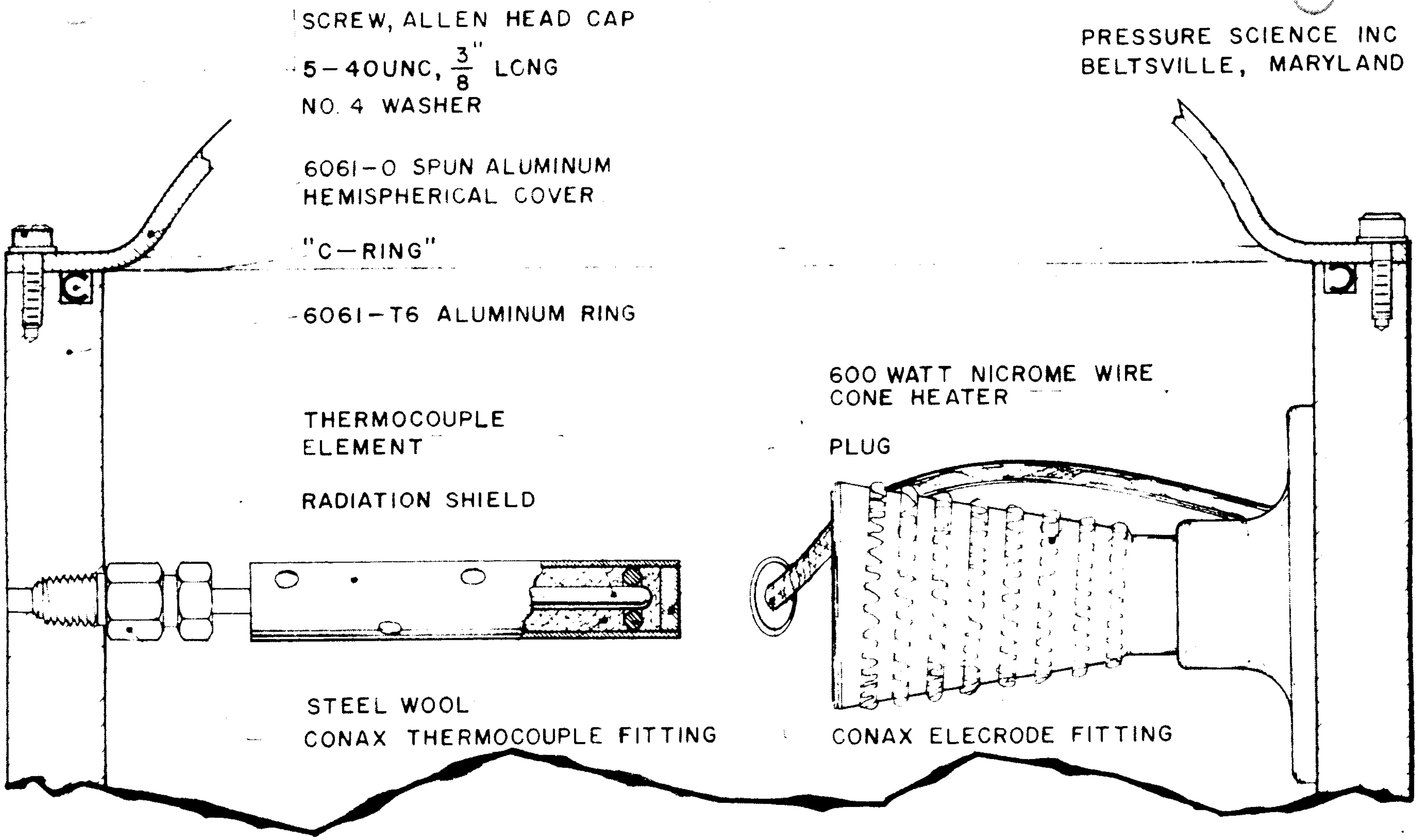
DETAIL OF THERMOCOUPLE GLAND



DETAIL OF ELECTRODE GLAND

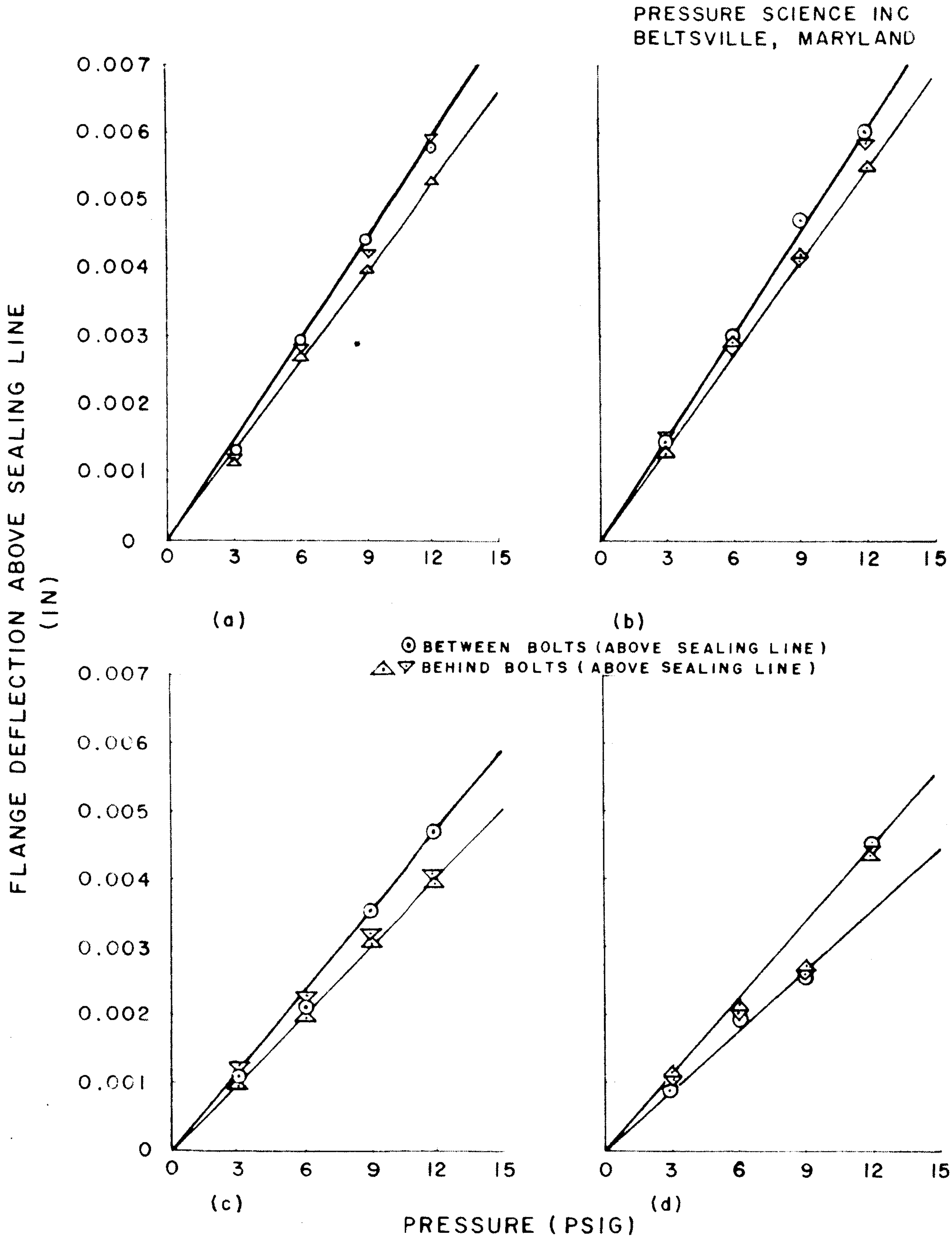
DETAILS OF ENCLOSURE GLANDS

FIGURE 11



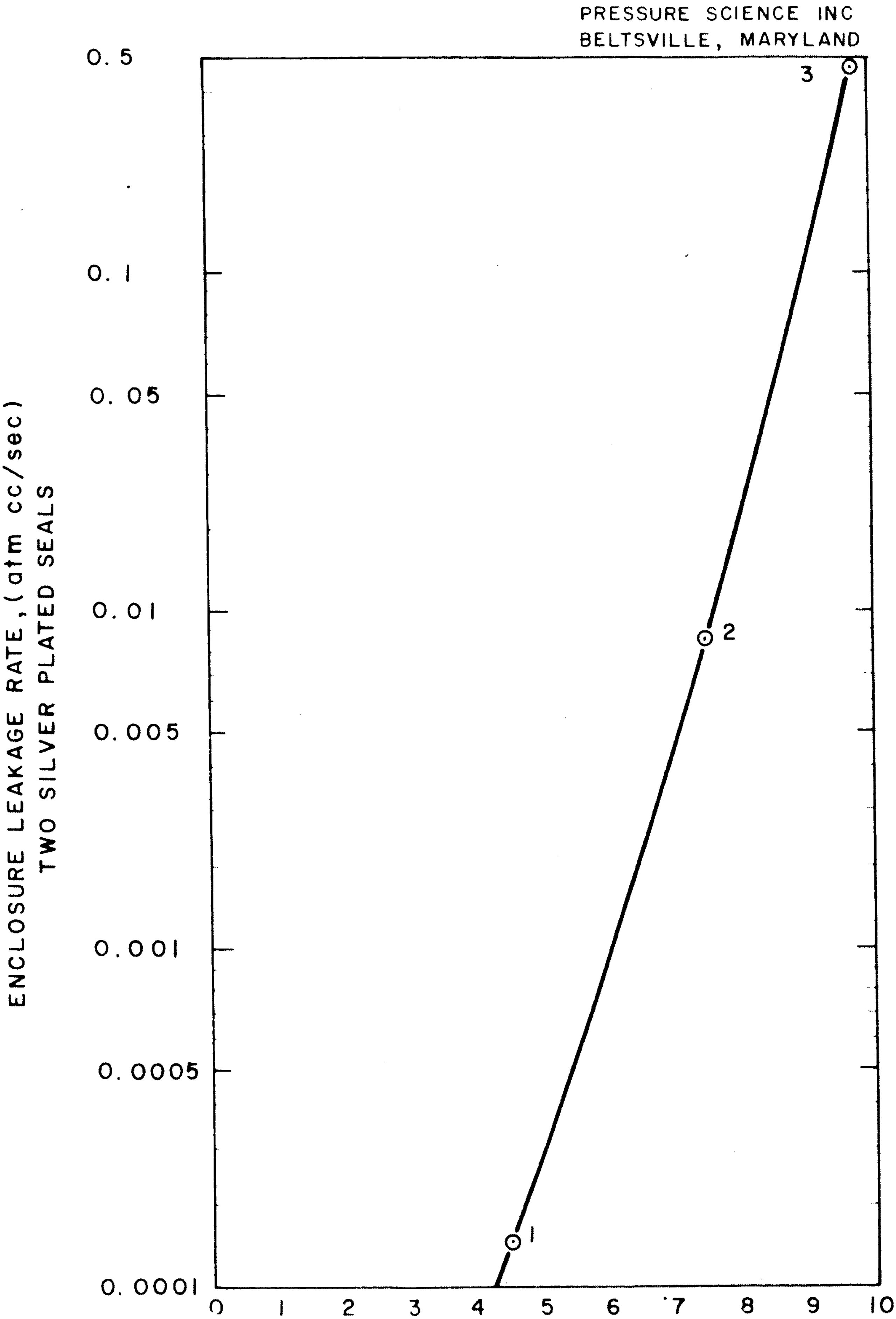
SCHEMATIC DIAGRAM SHOWING INSTALLATION OF HEATER AND THERMOCOUPLE

FIGURE 12



FLANGE DEFLECTION AS A FUNCTION OF ENCLOSURE PRESSURE AT 4 LOCATIONS.

FIGURE 13



MEASURED ENCLOSURE SEAL LEAKAGE RATE DURING VACUUM TESTING

FIGURE 14

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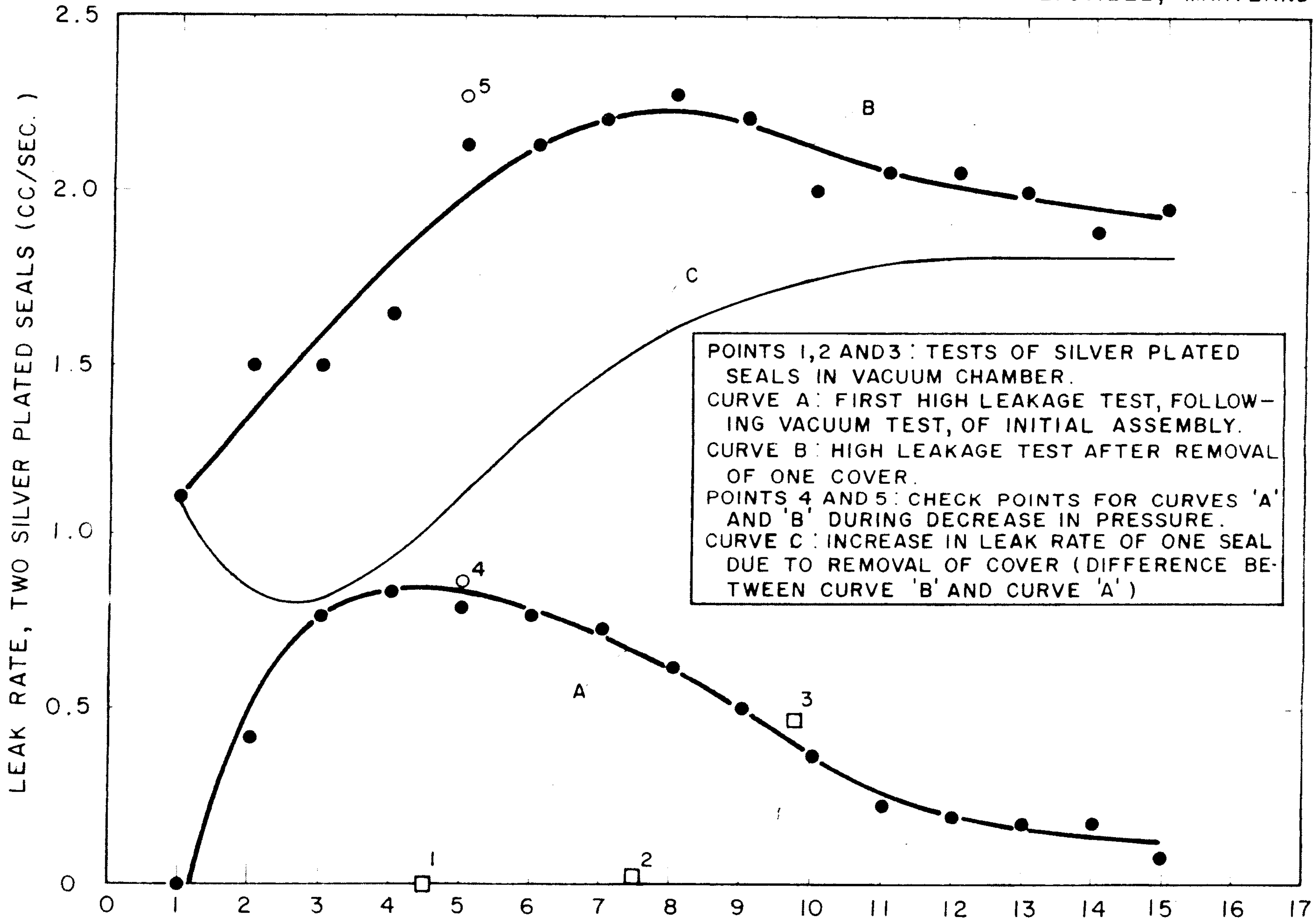

ENCLOSURE LEAKAGE RATE DATA

FIGURE 15

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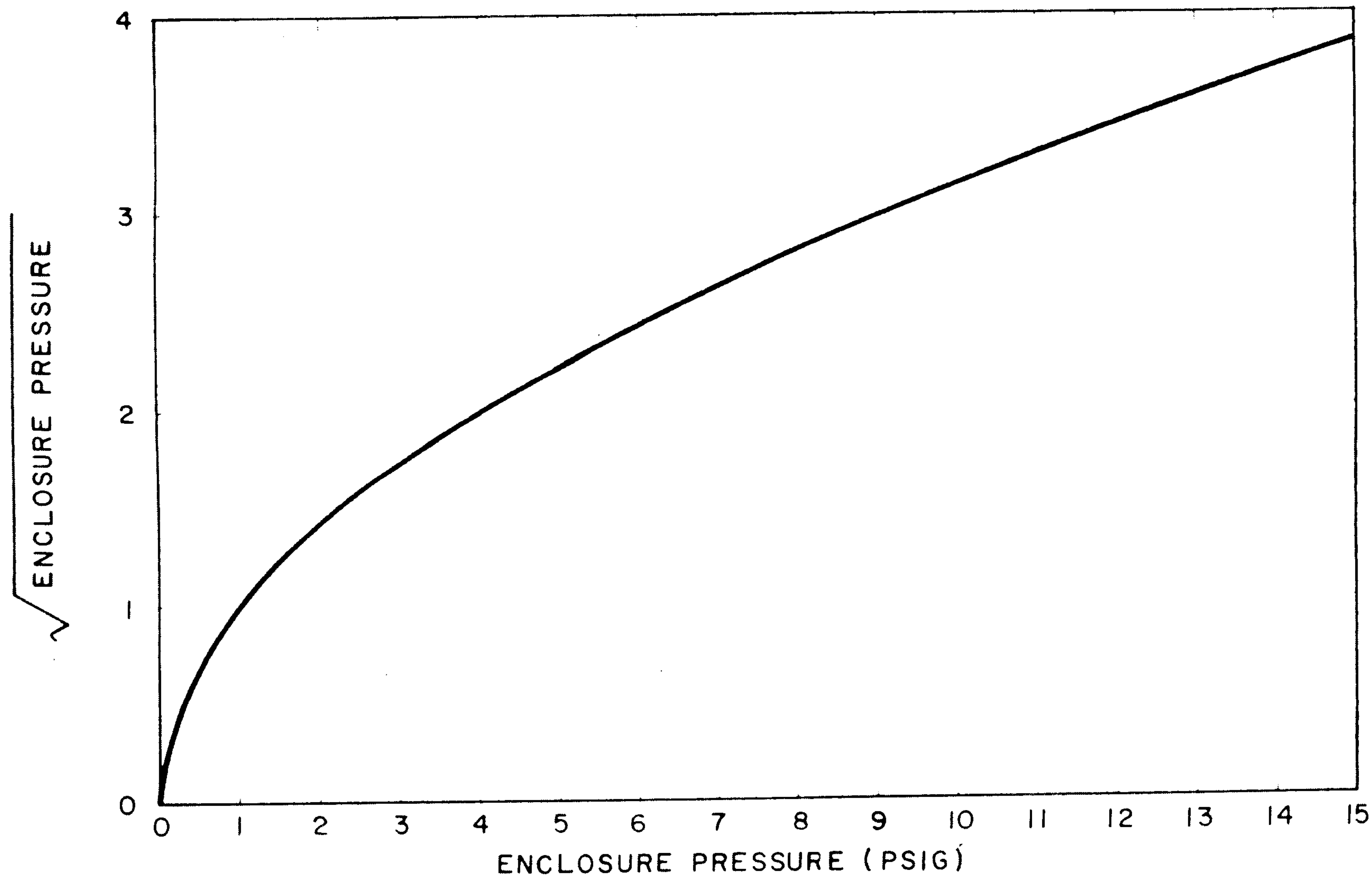

FORM OF ENCLOSURE LEAKAGE AS A FUNCTION OF PRESSURE ($Q \approx \sqrt{P}$)
PREDICTED FOR CONSTANT LEAKAGE PATH

FIGURE 16

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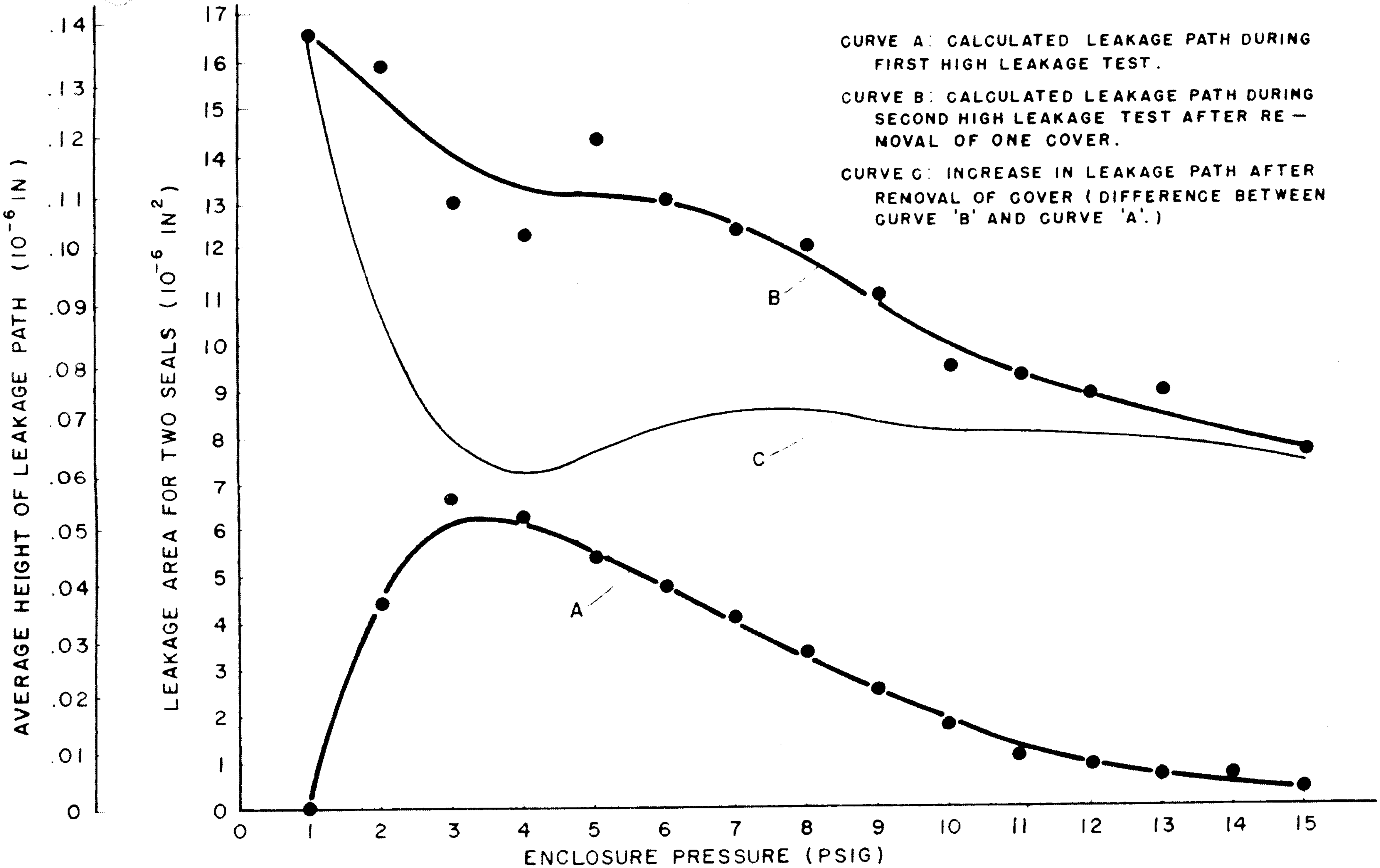

LEAKAGE PATH SIZE AS A FUNCTION OF PRESSURE (TOTAL LEAKAGE PATH CROSS — SECTIONAL AREA $\approx$ LEAKAGE RATE / $\sqrt{\text{ENCLOSURE PRESSURE}}$) FROM EXPERIMENTAL RESULTS OF HIGH LEAKAGE RATE TEST.

FIGURE 17

Table 6

FLANGE DEFLECTION DATA

(Enclosure with Gold-Plated Seals)

SIDE 2

Pressure (psig)	Deflection: Position 1 Behind Bolt	Position 2 Between Bolts	Position 3 Behind Bolt
0	0	0	0
3	.0012	.0013	.0012
6	.0027	.0029	.0028
9	.0040	.0044	.0042
12	.0053	.0058	.0059

	Position 4 Behind Bolt	Position 5 Between Bolts	Position 6 Behind Bolt
0	0	0	0
3	.0013	.0015	.0015
6	.0029	.0031	.0028
9	.0042	.0047	.0041
12	.0055	.0060	.0058

Table 6
(cont.)
FLANGE DEFLECTION DATA

(Enclosure with Gold-Plated Seals)

SIDE 1

Pressure (psig)	Deflection		
	Position 7 Behind Bolt	Position 8 Between Bolts	Position 9 Behind Bolt
0	0	0	0
3	.0011	.0011	.0010
6	.0022	.0021	.0020
9	.0031	.0035	.0031
12	.0040	.0047	.0040

	Position 10 Behind Bolt	Position 11 Between Bolts	Position 12 Behind Bolt
0	0	0	0
3	.0011	.0010	.0010
6	.0021	.0020	.0020
9	.0032	.0031	.0031
12	.0044	.0045	.0044

Table 7

C-RING HEIGHT AND CAVITY DEPTH DIMENSIONS

Enclosure A

Cavity Depth: 0.200 (Side 1)		Cavity Depth: 0.199 (Side 2)	
Gold-plated C-ring height		Gold-plated C-ring height	
Before service:	0.258 0.257	Before service:	0.260 0.257
After service:	0.221 0.212	After service:	not measured

Enclosure B

Cavity Depth: 0.204 (Side 3)		Cavity Depth: 0.200 (Side 4)	
Unplated C-ring height		Unplated C-ring height	
Before service:	0.256 0.253	Before service:	0.255 0.253
After service:	0.219 0.216	After service:	0.214 0.212
Silver-plated C-ring height		Silver-plated C-ring height	
Before service:	0.258 0.256	Before service:	0.255 0.253
After service:	0.214 0.213	After service:	not measured

Table 6

HIGH LEAKAGE TEST OF ENCLOSURE B

WITH SILVER-PLATED C-RINGS PRIOR

TO REMOVAL OF COVER B

Enclosure Pressure	Water collected in Graduated Cylinder	Elapsed Time	Enclosure Leakage Rate
(psig)	(ml)	(sec)	(cc/sec)
1	(no leak detected by set-up)		
2	33	80	0.413
3	36	47	0.767
4	37	44	0.840
5	35	44	0.795
6	35	45	0.778
7	35	48	0.730
8	35	57	0.614
9	36	72	0.500
10	36	98	0.367
11	38	175	0.217
12	38	195	0.195
13	34	192	0.177
14	28	157	0.178
15	26	169	0.072

Table 9

HIGH LEAKAGE TEST OF ENCLOSURE B

WITH SILVER-PLATED C-RINGS AFTER

REMOVAL OF COVER 3

Enclosure Pressure	Water collected in Graduated Cylinder	Elapsed Time	Enclosure Leakage Rate
(psig)	(ml)	(sec)	(cc/sec)
1	31	28	1.11
2	30	20	1.50
3	30	20	1.50
4	28	17	1.65
5	32	15	2.13
6	32	15	2.13
7	33	15	2.20
8	32	14	2.28
9	31	14	2.21
10	30	15	2.00
11	31	15	2.06
12	33	16	2.06
13	32	16	2.00
14	34	18	1.88
15	33	17	1.94

CALCULATIONS OF LEAKAGE RATES OF TWO 20-IN DIAMETER SILVER-PLATED C-RING ENCLOSURE SEALS FROM LEAK DETECTOR METER READINGS

Calibrated glass leak: 7.8×10^{-7} atm cc (He)/sec

Leak detector: Consolidated Electrodynamics Corporation type 24-110

Vacuum Pumping System: Central Scientific Company No. 94712 with Hyvac 28 two-stage pump.

Vacuum Test No. 1

A. Data

1. Enclosure pressure: 9 in. Hg abs. (19 parts N_2, 1 part He)

2. Calibrated glass leak rate detection
   Leak detector meter reading: 0.14
   Attenuator dial at 100X
   Therefore, calibrated leak reading = 14 divisions

3. Enclosure leak rate detection
   Leak detector meter reading: 0.433
   Attenuator dial at 300X
   Therefore, leak rate reading = 130 divisions

B. Calculation of enclosure leak rate

$$\text{Leak Rate} = 7.8 \times 10^{-7} \text{ atm cc(He)/sec.} \cdot \frac{130 \text{ div.}}{14 \text{ div.}} \cdot \frac{20 \text{ parts encl. gas}}{1 \text{ part He}}$$

Leak Rate = 0.145×10^{-3} atm cc/sec = 0.000145 atm cc/sec

Vacuum Test No. 2

A. Data

1. Enclosure pressure: 15.0 in. Hg abs. (29 parts N_2, 1 part He)

2. Calibrated glass leak rate detection
   Leak detector meter reading: 0.233
   Attenuator dial at 3X
   Therefore, calibrated leak reading = 0.7 divisions

3. Enclosure leak rate detection
   Leak detector meter reading: 0.26
   Attenuator dial at 100X
   Therefore, leak rate reading = 26 divisions

B. Calculation of enclosure leak rate

$$\text{Leak Rate} = 7.8 \times 10^{-7} \text{ atm cc(He)/sec.} \cdot \frac{26 \text{ div.}}{0.7 \text{ div.}} \cdot \frac{30 \text{ parts encl. gas}}{1 \text{ part He}}$$

Leak Rate = 8.7×10^{-3} atm cc/sec = 0.0087 atm cc/sec

Vacuum Test No. 3

A. Data

1. Enclosure pressure = 20 in. Hg abs.
   (39 parts N_2, 1 part He)

2. Calibrated glass leak detection
   Leak detector meter reading = 0.02 divisions
   Attenuator dial at 1X
   Therefore, calibrated leak reading = 0.02 divisions

3. Enclosure leak rate detection
   Leak detector meter reading: 1
   Attenuator dial at 300X
   Therefore, leak rate reading = 300 divisions

B. Calculation of enclosure leak rate

$$\text{Leak Rate} = 7.8 \times 10^{-7} \text{ atm cc(He)/sec.} \cdot \frac{300 \text{ div.}}{0.02 \text{ div.}} \cdot \frac{40 \text{ parts encl. gas}}{1 \text{ part He}}$$

Leak Rate = 0.469 atm cc/sec